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The fate of fertilizer nitrogen and phosphorus in field-sized watersheds

Marvin Allen Borcherding
Iowa State University

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by

Marvin Allen Borcherding

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INTRODUCTION

Rapid technological changes in the agricultural industry in the past 30 years have produced dramatic increases in grain production accompanied by substantial increases in fertilizer use. In Iowa in 1947, 6350 metric tons of nitrogen fertilizer were used. By 1976, usage of nitrogen fertilizer had increased to almost 950,000 metric tons, a 145 fold increase. Usage of phosphorus fertilizer has also increased substantially from 20,865 metric tons in 1946 to 420,822 metric tons in 1976 (Harmon and Duncan, 1978).

The large increase in nitrogen and phosphorus fertilizer usage has caused many questions to be raised as to the possible adverse effects that these chemicals may have on the environment, and ultimately on human health.

Many studies and yield tests have been conducted with nitrogen and phosphorus to determine the levels necessary for optimum crop growth. Levels of application for optimum crop growth, however, may not be the best levels for minimizing the adverse environmental effects that are sometimes associated with high levels of nitrogen and phosphorus applications. Studies attempting to identify the fate of fertilizer nitrogen and phosphorus in the soil-plant environment may be helpful in determining the best levels

of these nutrients for optimum crop production and minimization of adverse environmental effects.

A field study attempting to identify the transport of nutrients and herbicides from small, field-sized (6 to 7 ha) watersheds is presently underway in the Agricultural Engineering and Agronomy departments at Iowa State University, in cooperation with the U.S. Environmental Protection Agency. The research is being conducted in the Four Mile Creek basin in northwestern Tama County, near Traer, Iowa (Figure 1). The study was initiated in July 1975, and is expected to continue through 1983. The information gathered will be used to develop techniques useful in predicting losses of sediment, pesticides and nutrients in other areas of the state and country. This report will use data gathered in the study in an attempt to determine the fate of fertilizer applied nitrogen and phosphorus on 3 small, field-sized watersheds under conventional farming practices.

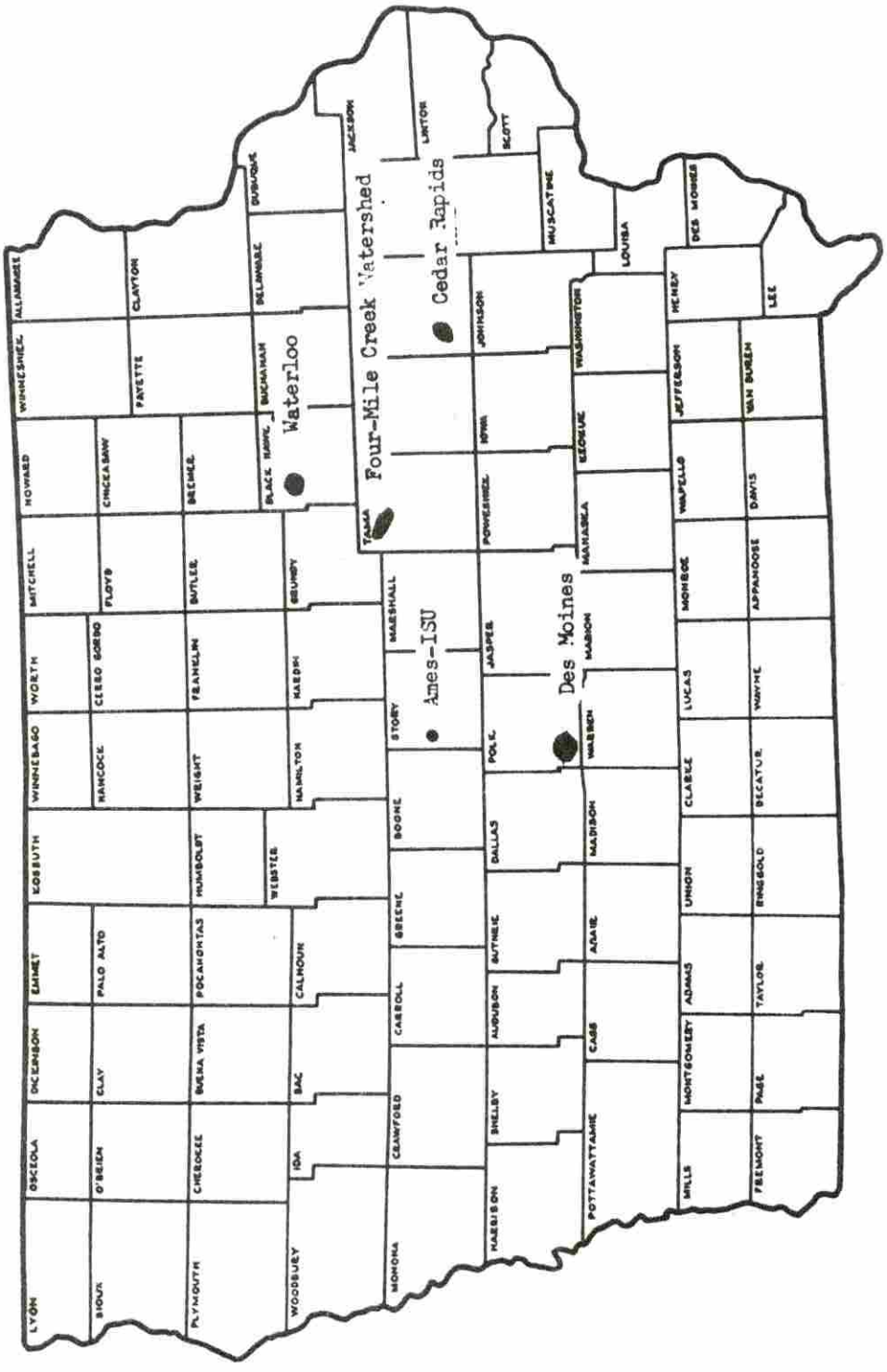


Figure 1. Location of Four Mile Creek watershed in Iowa

LITERATURE REVIEW

Nitrogen (hereafter referred to as N) and phosphorus (hereafter referred to as P) in the soil-plant environment have been studied for many years. The literature contains a large amount of information concerning N and P and the pathways and transformations that they undergo. This review will contain a description of those pathways and transformations that directly affect the fate of fertilizer applied N and P in the soil-plant environment.

Nitrogen Sources and Losses in the Soil-plant Environment

N is present in many different forms in the soil-plant environment. These forms can be divided into 2 major categories: organic N and inorganic N. The organic N is generally present as organic matter in living or dead root and plant tissues or as tissue in microbial bodies (Thompson and Troeh, 1973). Inorganic forms of N in the soil include: nitrous oxide (N_2O), nitric oxide (NO), nitrogen dioxide (NO_2), ammonia (NH_3), ammonium (NH_4^+), nitrite (NO_2^-), and nitrate (NO_3^-). When considering crop fertility, the last three are of most importance since they are the ionic forms of N found in the soil solution (Black, 1968). N present in the soil is readily transformed between the organic and inorganic forms through immobilization, decomposition and mineralization (Black, 1968).

Growing plants require large amounts of N for optimum growth to occur (Thompson and Troeh, 1973). Plants absorb most of the N that they use in the ammonium (NH_4^+) and nitrate (NO_3^-) forms (Tisdale and Nelson, 1966). There are several major sources of these forms of inorganic N.

The soil, itself, can supply a significant amount of N required for plant growth through decomposition and mineralization of organic matter. Olson et al. (1964), reported that N uptake by crops from plots in some Nebraskan experiments ranged from 34 to 157 kg/ha with no N fertilizer applied. In studies in Illinois, Viets (1965) estimated a range of 39 to 129 kg/ha of N uptake. High yields of corn have been reported during the first several years after cultivation of a bluegrass pasture when fertilized with P and no N (Thompson and Troeh, 1973). The rate of N mineralization is dependent on several factors, but can be measured in the laboratory. Stanford and Smith (1972) demonstrated that long-term as well as short-term mineralization can be measured reliably.

Fixation of atmospheric N by bacteria present in the soil, through a symbiotic relationship with a leguminous plant, can also be a significant source of N for plant growth. Ham and Caldwell (1978) estimated that N fixation by soybeans in their study ranged from 76 to 152 kg/ha. Leguminous crops such as soybeans and alfalfa can obtain

enough N through this symbiotic relationship to make additions of fertilizer N uneconomical (Thomsen and Herman, 1972). Investigators who have measured soybean yield response to N fertilization have reported small or no effects on yields (Lyons and Earley, 1952; Wagner, 1962).

The amount of N fixed by a legume crop may be large enough to provide a source of nitrogen for crops grown during the following season. Shrader and Voss (1972) estimated that soybeans can contribute as much as an equivalent of 17 kg of N for each metric ton of soybeans harvested (1 lb/bu), to the soil, which may then be available for plant growth the following season. The Iowa State University soils testing laboratory recommends reducing fertilizer N application by 45 kg/ha following a soybean crop, and up to a 157 kg/ha reduction after an alfalfa meadow crop (Voss, 1973).

If the soil cannot provide a sufficient level of N through mineralization, and the crop grown is not a legume, then fertilizer N must be added to the soil if yields are to be maintained at a high level. Fertilizer N is generally applied in large amounts to corn crops in the Midwest. In 1976 Iowa farmers used 946,099 t of N, mostly on corn (Harmon and Duncan, 1978). Johnson and Baker (1973) estimated that the average amount of fertilizer N applied to corn by farm operators in a drainage watershed in central Iowa was 140 kg/ha. A survey of farmers in another central Iowa watershed in 1976

and 1977 indicated that averages of 159 and 166 kg/ha were applied by farm operators to 96 and 97% of the corn grown in the watershed during the respective years (Baker et al., 1979). Iowa State University reported that corn yields at 3 locations for 2 years showed a positive yield reponse to N fertilization up to a rate of 202 kg/ha (Voss et al., 1975).

Another possible source of inorganic N to the soil can be atmospheric fixed nitrogen that reaches the soil in precipitation. Tabatabai and Laflen (1976) reported that 10 to 14 kg/ha of N can be added annually by rainfall in the Midwest. Although the N in rainfall is a relatively small amount, it becomes of greater importance when the soluble N level in runoff water is considered. Schuman and Burwell (1974) reported that the amount of soluble N in precipitation may be approximately 5 times that lost annually in surface runoff.

Two major crops grown in the Midwest, corn and soybeans, rely on 2 different sources of N to fulfill their N requirements (fertilizer N vs. legume fixation). The sources of N utilized by a crop can affect the level and pathways of N movement out of the soil-plant environment. There are several major pathways in the soil-plant environment that account for the majority of N removed or lost from the system.

Removal of N with the harvested crop usually accounts for a significant loss of N from the soil, when normal

fertilizer N rates are applied. Jolley and Pierre (1977a) estimated recovery rates of N in corn grain of 38.2 and 39.5% from 2 experiments when rates sufficient to give maximum yields were used. The percentage recovery in the grain decreased as the N application increased. Burwell et al. (1977) estimated that the average annual N content of the corn crop (grain and stalks) amounted to 104% of the average annual N applied when the recommended rate of N was applied. It was suggested that some of the crop's annual N needs were supplied by mineralization from the soil. At a high rate of N application (448 kg/ha) the average annual percentage of N recovered in the corn crop decreased to 48% of the average annual N applied. Ham and Caldwell (1978) measured from 255.5 kg/ha to 326.6 kg/ha of N in the residue and grain of soybean crops in their study. The sources of the N utilized by the soybeans were: N mineralized in the soil, N fixed by the soybeans, and a small amount from fertilizer N added (9.9 kg/ha to 12.8 kg/ha).

Large losses of N from the soil have been attributed to denitrification. Denitrification is generally defined as the biological reduction of NO3- and NO2- to gaseous forms of N in the soil, and occurs rapidly in warm soils, saturated with water and containing much readily decomposable organic matter (Black, 1968). The main sequence of products in biological denitrification has been established as: NO3- to NO2- to N2O

to N_2 gas, which then leaves the soil.

Studies have indicated that N lost through denitrification can account for a significant proportion of fertilizer N applied. Owens (1960) estimated that 33% of applied N was lost due to denitrification when he measured losses by N-15 analysis from 134 kg/ha of N applied to corn in a lysimeter study. Bremner and Shaw (1958) reported that under conditions conducive to denitrification, 80 to 86% of NO_3-N added to some soils was lost by denitrification in 5 days. Bolston et al. (1978) demonstrated in field experiments that denitrification can occur at very high rates. They reported that the highest rates occurred shortly after application of NO_3-N fertilizer to a soil maintained constantly wet. Jolley and Pierre (1977b) reported 26 and 32% of the N applied to 2 different soils, at rates necessary to achieve maximum yield, unaccounted for. At higher rates of N application, the N unaccounted for increased to 37 and 46%, respectively. Most of the N unaccounted for was presumed lost due to denitrification under the conditions of the study. Pomares-Garcia and Pratt (1978) reported 7.8 to 13.1% of the N applied to be unaccounted for, while studying the recovery of N-15 labeled N fertilizer. They concluded that most of the unaccounted for N was probably lost by denitrification.

Leaching of N below the root zone can also be a major pathway of N loss under certain conditions. Studies have been conducted analyzing the movement of N, mainly in the form of NO3-, through the soil profile. MacGregor et al. (1974) found appreciable amounts of NO3-N at depths below the root zone when an excess rate of N (268.8 kg/ha) was applied to an untiled Forman clay loam soil. Olsen et al. (1970) estimated that the bulk of the residual NO3-N in the soil moved through the profiles of corn plots at an average rate of about 30 to 40 cm per year. The NO3-N that moves beyond the corn root zone may continue to deep percolate or may appear in subsurface drainage. Burwell et al. (1977) reported a large increase in the amount of NO3-N present in a loess profile below the corn root zone after several years of excessive (448 kg/ha) N applications. They also calculated that at least 84% of the average annual soluble N discharged from the Treynor watersheds was in subsurface flow. Baker and Johnson (1977) suggested that tile drainage of agricultural land may cause more leaching loss of NO3-N due to increased percolation. Baker et al. (1975) reported that tile drainage water from fields in central Iowa was found to contain from 2.3 to 44.2 ppm of NO3-N, with an average of 21.0 ppm NO3-N from 1970 through 1973. The fields were not in continuous corn and had only a total of 224 kg/ha of NO3-N applied over 5 years.

N loss associated with surface runoff should also be considered when discussing the loss of N from the soil. Total N losses in the runoff water and sediment transported from agricultural land can amount to a significant proportion of the amount of fertilizer applied N. A study in west central Minnesota showed that an equivalent of 70% of the annually applied N was transported by sediment and surface runoff from continuous corn (Burwell et al., 1975). Most of the total N loss from the soil by surface runoff was contained in the sediment fraction. Burwell et al. (1977) reported that an equivalent of 6.5 to 12% of the fertilizer N applied to 2 contoured corn watersheds was lost due to surface runoff. Ninety-four percent of the total N discharged in the surface runoff was transported with sediment. They concluded that the total N loss in surface runoff is probably related to the amount of erosion that occurs. A study in western Iowa also concluded that total N losses were predominantly with the sediment. Johnson et al. (1979) reported that the average soluble N (NH4-N and NO3-N) loss per growing season with surface runoff from 4 watersheds was 0.35 kg/ha. The loss of soluble N was only 2% of the total N loss. The total N loss per growing season with conventional tillage ranged from 14 to 56 kg/ha.

Immobilization of soil N by the microbial population in the soil and the root system of the crop reduces the amount

of N available for plant usage. It remains unavailable until decomposition and mineralization of the organic matter occurs (Black, 1968). Kissel and Smith (1978) reported that 49% of applied N was recovered in the harvested crop. About 40% of the applied N remained in the soil as residual N, indicating that immobilization was a major factor causing low recovery of applied N by coastal bermudagrass on swelling clay soils. They concluded that immobilization of fertilizer N is more important on swelling clay soils than on coarse textured soils where N recovery has been reported to be between 75 and 100% of the applied N.

Stanford (1973) estimated that the average total amount of N immobilized by corn stover and roots, for 2 levels of N fertilization and including N initially contained in the residues, was approximately 140 kg/ha. It was also estimated that only 10 to 15% (15 to 20 kg/ha) of the residual N would be supplied to the next crop through mineralization.

Phosphorus Sources and Losses in the Soil-plant Environment

Phosphorus is present in the soil-plant environment in 2 major forms: organic and inorganic. The organic P in the soil is found in humus and other organic materials. Inorganic P is found in solid compounds in the soil, adsorbed to positively charged sites on clay minerals, and dissolved in the soil solution (Thompson and Troeh, 1973). The dissolved P in the soil solution is always in equilibrium with the solid and

adsorbed P. Most, if not all, of the P utilized by plants is inorganic orthophosphate, dissolved in the soil solution (Black, 1968). P in the soil moves back and forth between the organic and inorganic forms through mineralization and immobilization (Tisdale and Nelson, 1966).

Mineralization of P in the soil in a given year may or may not be a significant source of P available for plant growth. P mineralization from previous years, however, may affect the present level of available P (that P extracted from the soil using an acid fluoride solution, Bray No.1; hereafter referred to as AVL-P) in the soil (Black, 1968). If the level of AVL-P in the soil is high, due to a build up of previously mineralized P, or as a result of application of P fertilizers for many years, then the soil may be able to produce high yields of crops without application of fertilizer P. Novais and Kamprath (1978) studied the P supplying capacity of some soils with large amounts of residual P. They concluded that some soils in the southeastern United States could supply adequate P for corn for 1 to 6 years without additional P fertilizer. If, however, the level of AVL-P is not adequate, then additional fertilizer P may be added to provide the soil with an adequate level of P for maintenance of high crop yields.

Most soils in the Midwest, on which corn or soybeans are grown, receive annual application of P fertilizer. In 1976,

the Iowa Department of Agriculture reported that 420,822 t of P_2O_5 were applied to Iowa farm land (Harmon and Duncan, 1978). Johnson and Baker (1973) estimated that an average of 90 kg/ha of P_2O_5 was applied annually to row crops in a central Iowa watershed. A survey in another central Iowa watershed during 1976 and 1977 indicated that averages of 55 and 62 kg/ha of P_2O_5 were applied annually to 96% and 97% of the corn acres for the respective years (Baker et al., 1979).

Fifty percent of the soils tested by the Iowa State University soils testing laboratory between 1968 and 1973 contained very low levels of P, indicating that addition of P fertilizer would be profitable (Eik, 1975). For profitable corn production in Iowa, an application of 50 to 135 kg/ha of P_2O_5 fertilizer is recommended, depending on the soil test results (Benson, 1976).

Precipitation contains a small amount of P. Tabatabai and Laflen (1976) reported that inorganic P added by precipitation amounts to about 0.1 kg/ha of P annually in Iowa. This small amount was considered insignificant.

Losses of P from the soil-plant environment take place through several pathways. One of the major pathways of P loss is uptake and utilization by crops grown on the soil. In a technical assessment of nonpoint pollution in Iowa, it was estimated that the harvested portion of several major crops grown in the state removes 17 to 28 kg/ha of total P from the

soil. A minimum of those quantities of P need to be applied each year as manure or fertilizer in order to maintain profitable yields (Harmon and Duncan, 1978).

Burwell et al. (1977) reported that the average P content in mature corn grain and stalks for a watershed near Treynor, Iowa was 26 kg/ha, 64% of the average annual application of fertilizer P. The corn crop on another watershed in the same study used 33 kg/ha of P, 49% of the average annual application of fertilizer P. Ham and Caldwell (1978) reported that additions of P fertilizer, regardless of placement, increased the seed yield and total plant P of soybeans in their study. Approximately 1/3 of the 35 kg/ha of P applied to the soybeans was recovered in the beans.

Phosphorus loss from the soil can also occur through surface runoff; P loss in runoff can be either soluble P in the water or P in the sediment fraction of the runoff (Harmon and Duncan, 1978). Phosphorus loss in the sediment may be measured in 2 forms: total P or AVL-P. The amount of soluble and AVL-P lost with surface runoff is generally low compared to the amount used by crops, but losses of total P may be quite high. Burwell et al. (1977) reported the average annual loss of P (soluble and available) in surface runoff to be less than 1.0 kg/ha for each of 4 watersheds. The P loss was less than 2% of the average annual P application. The study also indicated that the majority of the P lost was

transported with sediment, 82% in this case.

Johnson et al. (1979) reported small growing season losses of soluble P during the growing season (generally less than 0.3 kg/ha) from watersheds in western Iowa, in a study of several different tillage methods. During the first year of the study (1973), when total P loss was measured in the runoff, 80 to 99% of the P losses for each treatment were associated with sediment. The large P losses associated with sediment make it possible to lose large amounts of P, if sediment loss is high, as was the case in the first year of their study when the total P loss from conventional tillage was close to 40 kg/ha. Since 37 kg/ha of P were applied each year, the loss of total P was more than 100% of the amount of P applied. During the last 2 years of the study (1974 and 1975), P loss in the sediment was measured as AVL-P. The losses of AVL-P for the 2 years from conventional tillage were 1.0 and 0.7 kg/ha, respectively.

Hanway and Laflen (1974) found that annual surface runoff losses of soluble P varied from 0.44 to 1.06 kg/ha from 4 tile outlet terrace systems that were studied. They also found the total P loss at each site to be highly correlated with the amount of sediment in the runoff.

A small amount of soluble P is sometimes lost with subsurface flow, but the loss is generally insignificant. Baker et al. (1975) found P losses with subsurface drainage to be

negligible during 3 years of study on several small field plots. These findings were consistent with those of Hanway and Laflen (1974), since subsoils through which tile drainage flows are generally low in P and extract much of that leached from the surface.

Phosphorus added to the soil in fertilizer materials is not completely available for plant use. Olsen (1975) concluded that the rate of dissolution of phosphate from soils and minerals is important in determining the value of the material as a source of P to plants. Phosphorus compounds can be divided into 3 groups based on solubility: water soluble P compounds, those not soluble in water but soluble in ammonium citrate solution, and those insoluble in ammonium citrate (Olson et al., 1971).

Phosphate rock, which is the basis of most P fertilizers, varies in solubility, depending on the source of the rock. Chien (1977) studied the solubility of 3 phosphate rocks and indicated that the phosphate rocks differed in their solubility and that each rock apparently contained 2 fractions which also differed in solubility. Almost all of the phosphate rock material is converted to a more soluble form through phosphate manufacturing processes before being sold as P fertilizers (Olson et al., 1971).

When fertilizer is added to the soil, reactions occur that can reduce the availability of P in the fertilizer mate-

rial. The formation of crystalline products and reduction of water solubility can be caused by several different mechanisms, including the reaction of P with clay minerals and with soluble, exchangeable, and oxide forms of aluminum, iron and calcium (Griffin and Hanna, 1967). These authors reported that several New Jersey soils required from just over 1.1 kg/ha to more than 90 kg/ha of fertilizer P to effect a change of 1.1 kg/ha in the soil test measurement.

Vijayachandran and Harter (1975) studied soils with a broad range of characteristics normally associated with P adsorption. They concluded that aluminum and organic matter in the soil are primarily responsible for P adsorption. Franklin and Reisnauer (1960) estimated that from 1282 to 8484 kg/ha of P would have to be added to 3 Washington soils to permanently eliminate plant response to P fertilizers.

Some studies have indicated that the pH of a soil affects the P fixation capacity of the soil. Cho and Caldwell (1959) studied forms of P and P fixation and compared methods of determining AVL-P in several Minnesota soils. They observed the capacity of the soils to "fix" P from added KH_2PO_4 and found that the P fixation capacity of soils increased with departure from a pH near neutrality. They also found that the amounts of AVL-P determined were generally larger with methods using strong acids than with methods using weak acids. Chien (1978) studied the reaction

of various phosphate materials with Weston soil (pH 4.5). The results indicated that the materials varied in the amount of water soluble P following reaction with the soil. He concluded that one of the phosphate materials tested (Rhenania phosphate) would be better than the rest as a potential P fertilizer source for tropical acid soils with relatively high P retention capacity.

MATERIALS AND METHODS

Samples of surface runoff water were taken from 3 small, field-sized watersheds established within the Four Mile Creek basin. Two of the watersheds were in a corn-bean rotation, corn and soybeans being grown on each of the watersheds in alternate years; the third watershed was in permanent pasture. To collect the samples, flow measuring devices were constructed and automatic sampling equipment installed at each of the sites.

Samples of runoff water were also taken from larger watersheds, which vary from approximately 150 ha to 5000 ha in area. The samples were obtained from the larger watersheds by use of hand sampling equipment.

Subsurface water was sampled from 8 tile outlets entering Four Mile Creek. The subsurface samples were taken manually.

The locations of the 3 field-sized watersheds within the Four Mile Creek basin are shown in Figure 2. The watersheds are identified as sites 1, 2, and 3. Sites 1 and 2 are located in the SE1/4 of the NE1/4, Sec. 10, T-86N, R51W of the 5th principal meridian. The watershed at site 1 is approximately 6 ha in area; the watershed at site 2 is approximately 7 ha in area. Land slopes range from 1 to approximately 10% on site 1, and 1 to approximately 8% on site 2. The soil types on both watersheds are the same, consisting of Tama

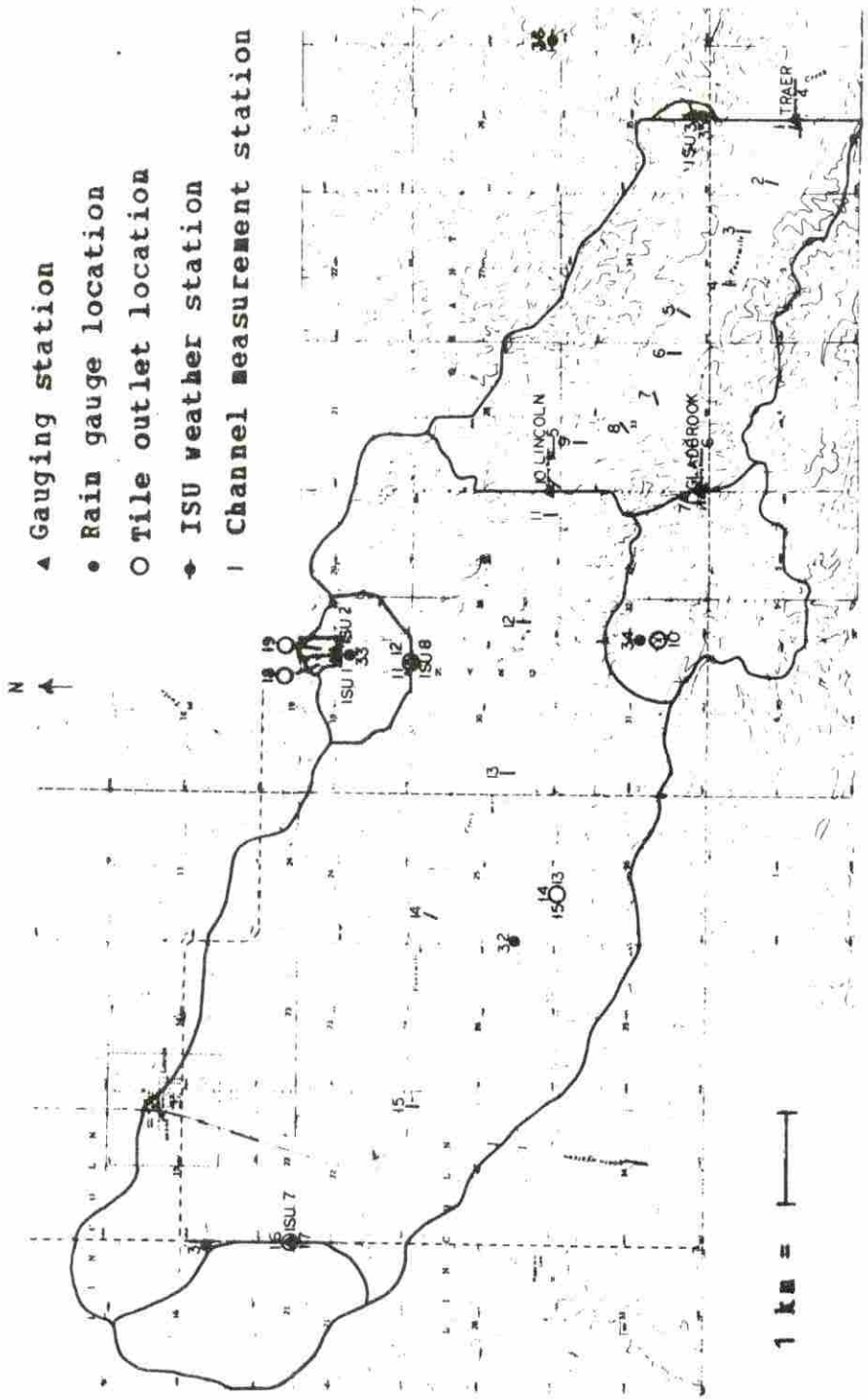


Figure 2. Four Mile Creek watershed instrumentation

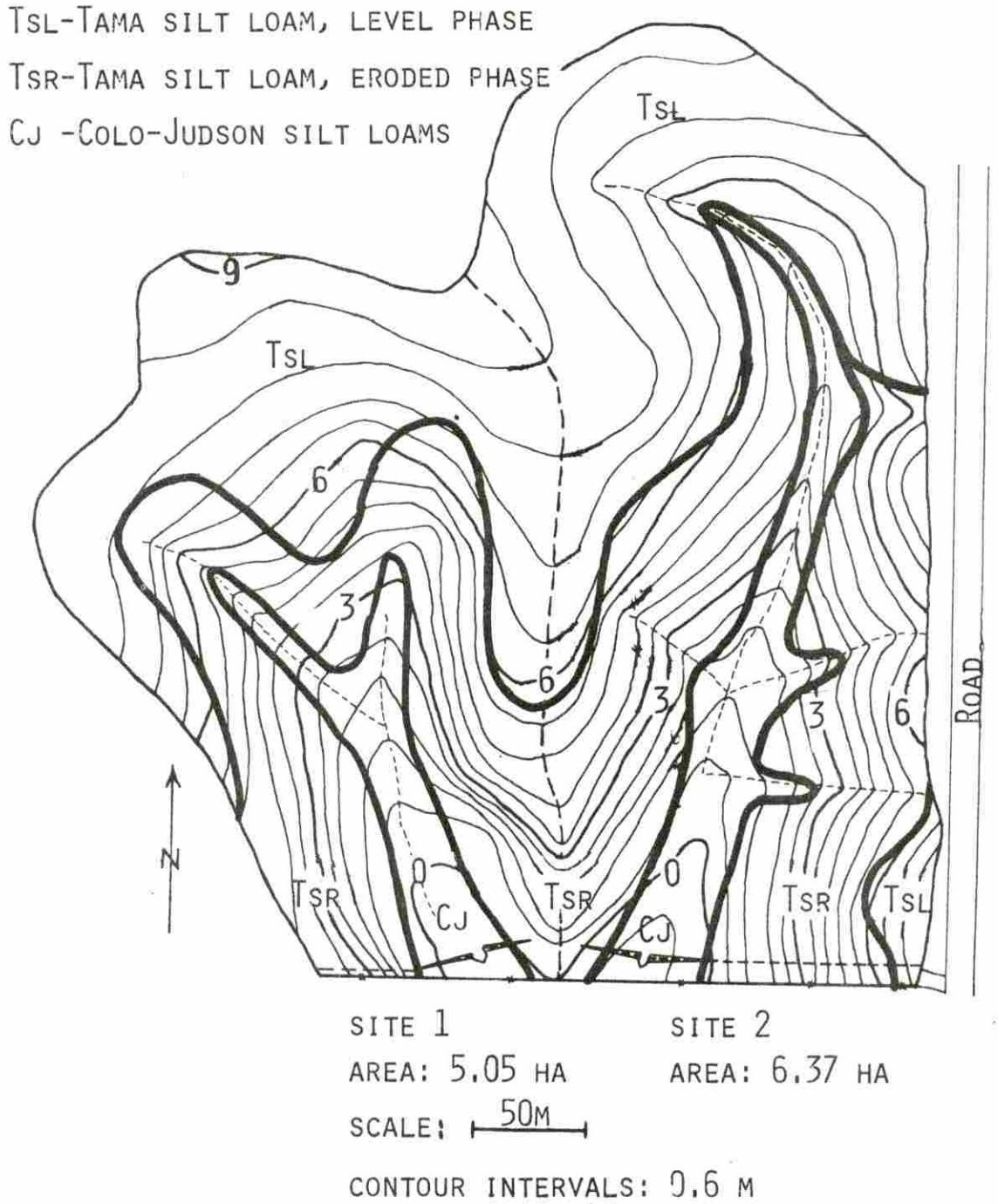


Figure 3. Soil map of sites 1 and 2

silt loam 1-3%, Tama silt loam-eroded 6-8%, and Colo-Judson silt loams 2-4% (see Figure 3). Both sites 1 and 2 have been farmed in row crops for many years, with corn and soybeans being the dominant crops. The amount of fertilizer applied in years previous to the initiation of the project was approximately 114 kg/ha of N, 24 kg/ha of P and 47 kg/ha potassium (hereafter referred to as K) per year on the corn, with smaller amounts of P and K (and no N) on the soybeans. Tillage has been conventional with no erosion control practices, however the operator seeded grass waterways in the spring of 1976 to reduce erosion.

Fertilizer was applied to sites 1 and 2 each spring before planting during the first 3 years of the study (1976-1978). In 1976 site 1 was planted to soybeans and received 34 kg/ha of P and 56 kg/ha of K, which were incorporated by plowing with a moldboard plow; site 2 was planted to corn and received 135 kg/ha of N, 39 kg/ha of P, 65 kg/ha of K, 22 kg/ha of sulfur and 6 kg/ha of zinc, which were incorporated by disking. The fertilizer application rates and tillage operations remained the same for both crops during 1977 and 1978 (no sulfur or zinc). The corn and soybean crops were alternated between sites 1 and 2 each year.

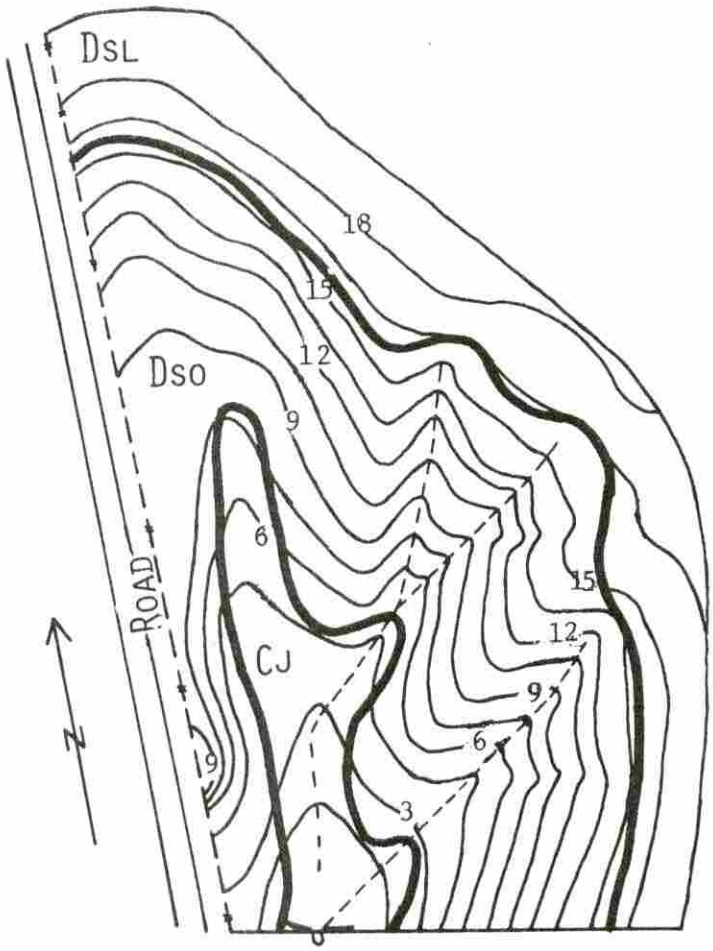
The fertilizer was all in solid form and was double spread by a local dealer to ensure a uniform application. The N in the fertilizer was in the form of urea and diammonium

phosphate, the P in the form of concentrated superphosphate and diammonium phosphate, and the K in the form of potassium chloride. An effort was made to measure the amount of fertilizer spread. The results indicated that the fertilizer was applied with a reasonably uniform distribution. The rate of fertilizer application required for each crop was determined from soil tests, performed by the Iowa State University soils testing laboratory.

Site 3 is located in the W1/2 of the SE1/4, Sec. 35, T86N, R15W. The watershed at site 3 is approximately 6 ha in area. The soil types on this watershed consist of Downs silt loam 1-3%, Downs silt loam-eroded rolling phase 12-16% and Colo-Judson silt loams 1-3% (Figure 4). Site 3 has been in continuous permanent bluegrass and smooth bromegrass pasture for approximately 10 years, but observation indicates that it may have been farmed in row crops sometime in the past. Fertilizer has been applied to the pasture for about the past 10 years at a rate of approximately 67 kg/ha of N per year.

Fertilizer was not applied to site 3 in 1976, but in 1977 and 1978 fertilizer was applied at the rate of 78 kg/ha of N, 19 kg/ha of P and 19 kg/ha of K. The fertilizer was applied during the spring in the same forms as for sites 1 and 2, and was spread by a local dealer.

Instruments were installed at the 3 field-sized watersheds during the fall of 1975 and the spring of 1976. A



SITE 3
AREA: 5.93 HA
SCALE: 50M
1.5 M CONTOUR INTERVALS

DSL-DOWN SILT LOAM, LEVEL PHASE

DSO-DOWNS SILT LOAM, ERODED ROLLING PHASE

CJ-COLO-JUDSON SILT LOAMS

Figure 4. Soil map of site 3

4 ft, HL, stainless steel flume (Agricultural Research Service, 1962) was installed in the waterways at each of the watersheds, to collect and measure surface runoff. A plywood approach box was constructed on the upstream side of each flume to mix the runoff, provide a symmetrical approach, and provide a location where a sampler intake could withdraw a well-mixed sample. Two FW-1 stage recorders (Agricultural Research Service, 1962), one with a 6 hr and one with a 24 hr clock rotation, were installed on each of the flumes. The samples of surface runoff were taken by automatic samplers designed to take 4 liter samples. The runoff samples were stored in a refrigerator at the site until collection by project personnel. Five ports, at various heights, were installed on one of the walls on each of the flumes. These ports allowed runoff water to flow into bottles as the water rose in the flumes, providing additional samples of the runoff water in the event of failure of the automatic samplers.

Recording rain gauges (Agricultural Research Service, 1962) were installed at all 3 sites to measure precipitation. A collection device with automatic cover was also installed at site 2 to take large samples of precipitation to be analyzed for nutrient content.

A tile line (12.7 cm in diameter) was discovered along the waterways at each of sites 1 and 2. Tubes were inserted

into the lines to obtain samples of subsurface flow to be analyzed for nutrient content.

Soil sampling was conducted at all 3 sites during the growing seasons of 1976, 1977, and 1978. Soil core samples were taken with a soil auger (7.5 cm in diameter) to a depth of 150 cm, and divided into 9 layers defined as: 0-1, 1-7.5, 7.5-15, 15-30, 30-45, 45-60, 60-90, 90-120, 120-150 cm below the soil surface. The first set of core samples taken in May 1976 had the top 2 layers combined into a 0-7.5 cm layer. Core samples were taken 3 times during each growing season (at planting, mid-summer, and after harvest) at 8 locations at site 1, 8 locations at site 2, and 5 locations at site 3. The sampling locations are identified in Figures 5 and 6. Additional samples of the top 4 layers (0-1, 1-7.5, 7.5-15, and 15-30 cm) were taken at sites 1 and 2 between the times of the deeper core samples. These additional samples were taken with a split tube sampler (1.9 cm in diameter). Sixteen subsamples were taken scattered throughout each of the 3 soil areas at each site (Figure 3). The subsamples were composited to make one sample for each soil area, 3 samples at each site.

All water samples (surface runoff, tile flow, and precipitation) were analyzed for NH_4-N, NO_3-N, PO_4-P, and Cl. The colorimetric phenate method was used for NH_4-N determinations, the cadmium reduction method for NO_3-N, the ferric

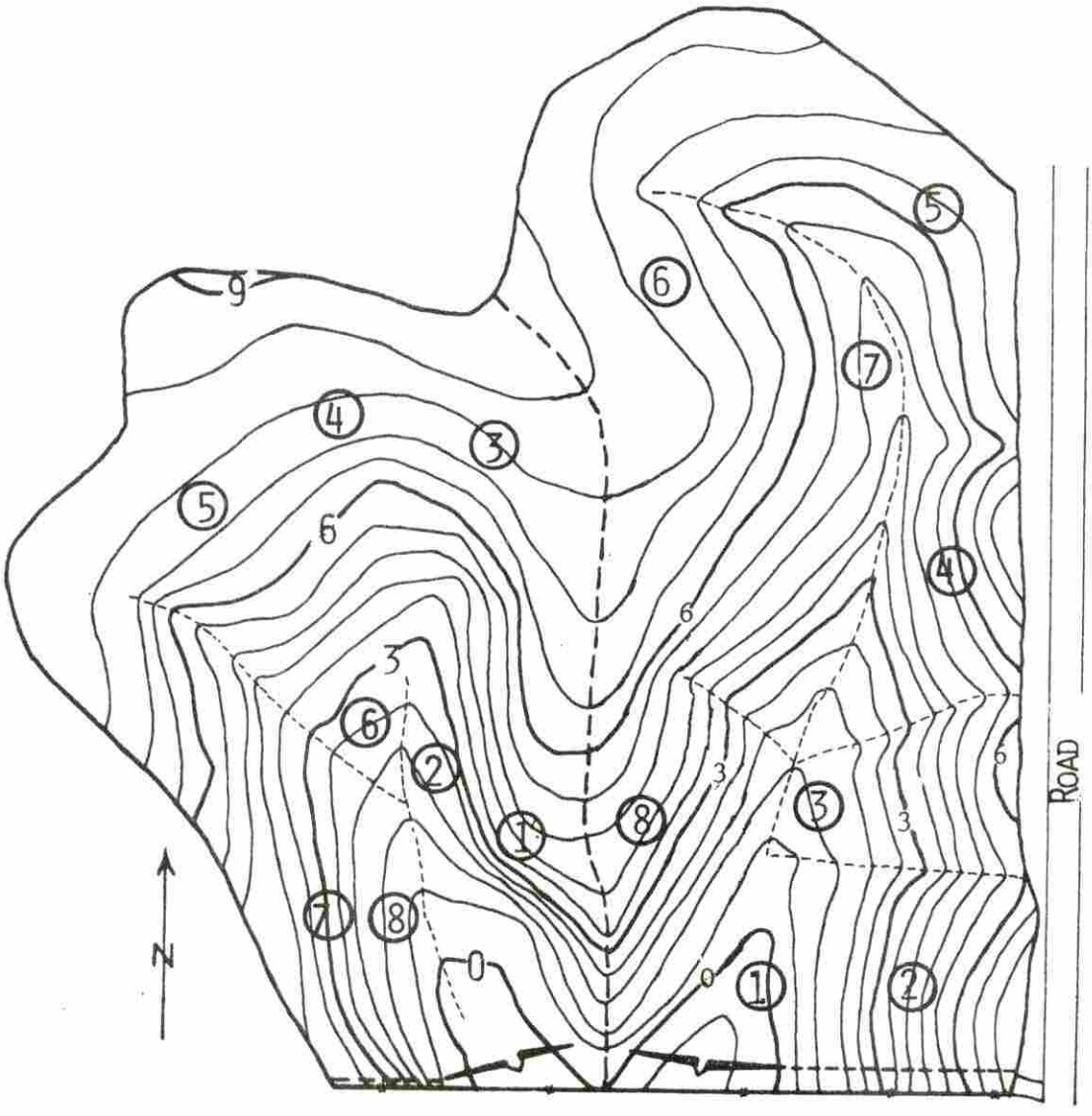


Figure 5. Location of soil core samples at sites 1 and 2

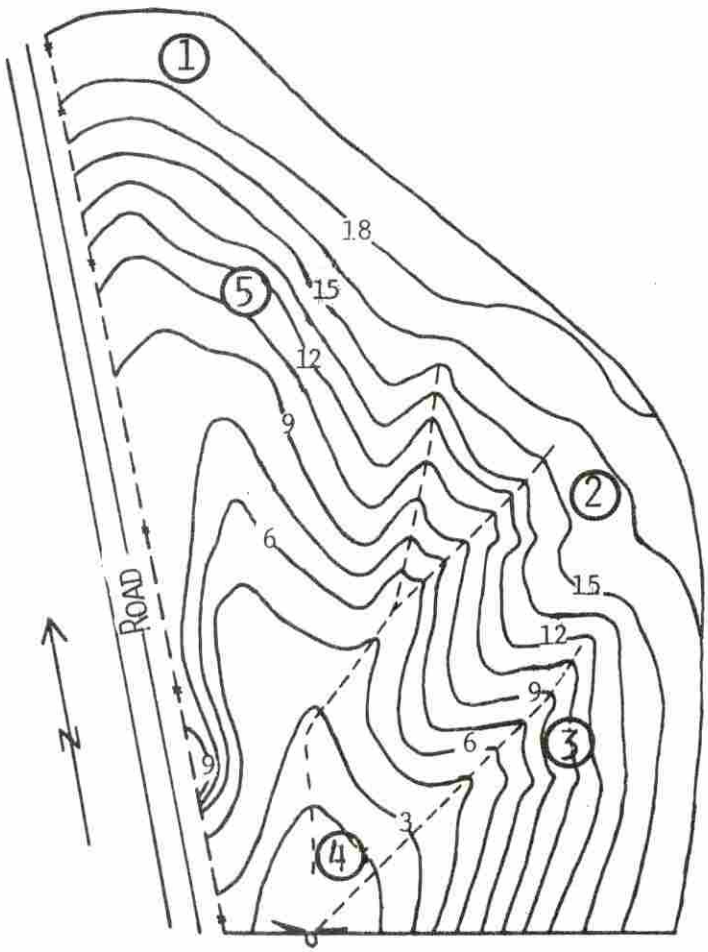


Figure 6. Location of soil core samples at site 3

thiocyanate method for Cl, and the phospho-molybdate, ascorbic acid reduction method for PO4-P analysis (Environmental Protection Agency, 1974). For runoff samples with sufficient sediment, extractable NH4-N and AVL-P were measured in the sediment. Flow data for the surface runoff were combined with concentration data to calculate soluble nutrient and sediment loads. Sediment AVL-P and total N loads were calculated by combining sediment load data with the AVL-P concentrations in the sediment and total N analysis for the surface layer of the original (150 cm) soil core samples. Precipitation data were combined with concentration data to calculate total soluble nutrients deposited. Soil samples taken to 150 cm and 30 cm depths were analyzed for moisture, NH4-N, NO3-N, PO4-P, Cl, extractable NH4-N, and AVL-P. In addition, the original (150 cm depth, May 1976) set of soil core samples was analyzed for total N, total P, percent organic matter, soil pH, and buffer pH. The soil soluble NH4-N, PO4-P, and Cl were extracted with water, 5 times the weight. The extractable NH3 was extracted with 1NK2SO4, 5 times the weight (Bremner, 1965). The AVL-P was determined using 10 times the weight of acid fluoride solution; Bray No. 1 (Olsen and Dean, 1965). Total P and total N were determined with a sulfuric acid hydrogen peroxide digestion (Environmental Protection Agency, 1974).

Samples of the corn and soybean grain and residue were taken at sites 1 and 2 at the end of each growing season. Total yield of the grain and residue at sites 1 and 2 was estimated from these samples. Fourteen samples were taken from the corn field in 1976 and 6 samples in 1977 and 1978. Six samples were taken from the soybean field each year. The samples were also analyzed for N and P to determine the amounts of nutrients utilized by the grain and residue of the crops each year. The sulfuric acid hydrogen peroxide digestion (Environmental Protection Agency, 1974) was used in analyzing the grain and residue samples. No samples were taken to determine the yield of grass from the permanent pasture.

RESULTS AND DISCUSSION

Crop Use of Nitrogen and Phosphorus

The yields of corn and soybeans from the 2 fields at sites 1 and 2 were within the range of yields normally expected from the soil types present during the first 3 years of the study. A small yield reduction was observed for soybeans in 1976 and corn in 1977, probably due to dry weather that caused some moisture stress during both years. In 1978 a small increase in yield for both corn and soybeans was observed due to favorable weather conditions for crop growth.

The N content of the corn and soybean crops (grain and residue) is presented in Table 1. The N content of the corn far exceeded the amount of fertilizer N applied each year, ranging from 126 to 140%. These results suggest that the corn crop was utilizing additional sources of N to fulfill its N requirements. Since the corn was grown in rotation with soybeans, excess N fixed by the soybeans probably remained in the soil to provide a source of N for the corn crop. Mineralization of N in the organic matter of the soil could also have been a significant source of N. Precipitation also contributed a small amount of N (Table 2), but was probably an insignificant source. The amount of N removed from the field in the corn grain ranged from 87 to 95% of the annual application rate. These results indicate that the

potential for loss of fertilizer N to the environment was probably very low, with the rate of N applied, under the existing field conditions.

No fertilizer N was applied to the soybeans in any of the 3 years of the study. The major sources of N for the soybeans were the N fixed from the atmosphere by the soybeans themselves, and N mineralized from organic matter in the soil. No attempt was made to measure either of these sources. It was assumed that the amount of N fixed and mineralized was adequate for optimum crop growth and that there was some additional fixed or mineralized N remaining in the soil at the end of the growing season that served as a potential source of N for the next season's corn crop.

The P content of the corn and soybean crops (grain and residue) is also presented in Table 1. The P content of both the corn and soybeans amounted to a significant portion of the fertilizer P applied each year. The corn crops contained an equivalent of 77 to 85% of the annual application of fertilizer P, while the soybean crops contained 47 to 65% of the level of fertilizer P applied. The P removal with the corn grain amounted to an equivalent of 59 to 67% of the fertilizer P applied. The P in the harvested portion of the soybeans also amounted to a large proportion (41 to 59%) of the amount of fertilizer P applied. Since the corn crops appear to be utilizing and removing an equivalent of more of

the P applied than the soybean crops, there may be more P available for loss to the environment or accumulation in the soil under the soybean crops than under the corn crops at these levels of P applications and these field conditions.

The yield of grass from the pasture at site 3 was not measured. The crop use of N and P, however, may be reflected in the N and P levels of the soil core samples taken during various times of the season.

Distribution and Movement of Nitrogen and Phosphorus in the Soil Profile

The soil core samples taken at sites 1, 2, and 3 provide information about the distribution of N and P in the soil profile at various times of the growing season. Nutrient levels measured in the soil samples included: NH4-N, NO3-N, PO4-P, extractable NH4-N, and available P.

Variability in the nutrient content of the soil profiles across the fields at the 3 sites makes it difficult to establish statistically significant differences from one soil area to the next (Tables 3 through 10). Variability of nutrient levels in soil core samples across watersheds has been reported in other watershed studies (Smith et al., 1978). For comparison purposes, the nutrient levels in the soil profile at each site for a given sampling time were determined by averaging the nutrient levels of the sampling locations at each site.

The fertilizer N applied was in the form of urea and diammonium phosphate, causing large increases in NH4-N and extractable NH4-N in the surface layers of the soil early in the growing season (Table 3). NH4-N is rapidly changed to NO3-N by microbes in the soil through the process of nitrification. Large increases in the levels of NO3-N in the upper layers of the soil early in the growing season are evidence of the change (Table 6). Since NO3-N has been shown to be more subject to movement in the soil profile than NH4-N, the discussion of the fate of fertilizer N will be mainly concerned with the distribution of NO3-N in the soil profile. The NO3-N concentrations in the soil profile for 3 sampling dates in 1977 from site 1, are presented in Figure 7 and Table 4.

The NO3-N concentrations in the upper layers of the soil profile increased after fertilization of corn crops, indicating that some downward movement of N occurred. As the season progressed the NO3-N concentrations in the upper layers decreased without an increase in the NO3-N concentrations in the lower layers of the profile. Similar trends were observed under corn during 1976 and 1978. The concentrations of NO3-N remaining in the soil profile at the end of each growing season for each site are presented in Figures 8, 9, and 10. There did not appear to be any significant movement of NO3-N into the lower layers of the soil profile (90-150 cm) at any

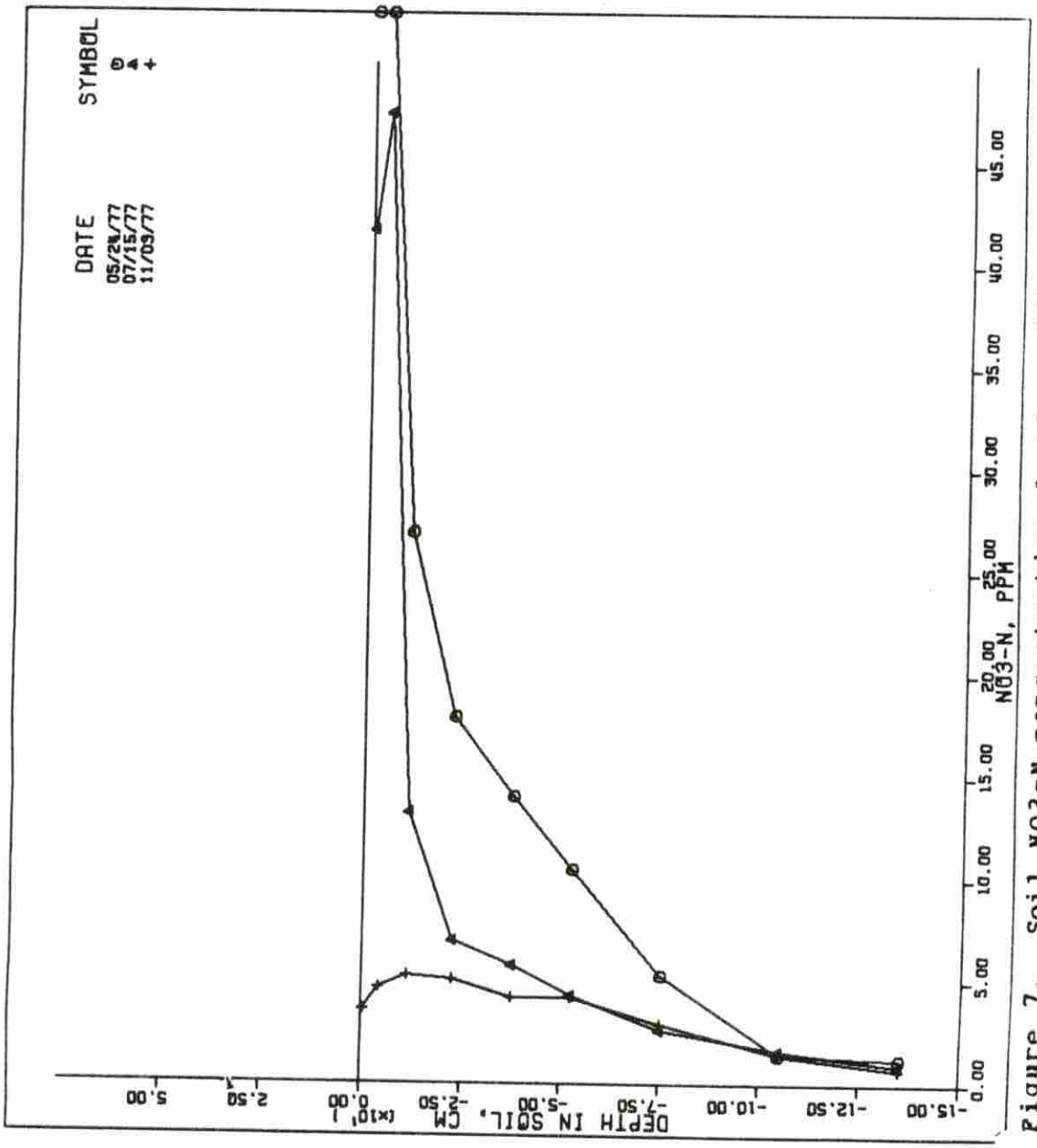


Figure 7. Soil NO3-N concentration depth profiles at site 1, 1977

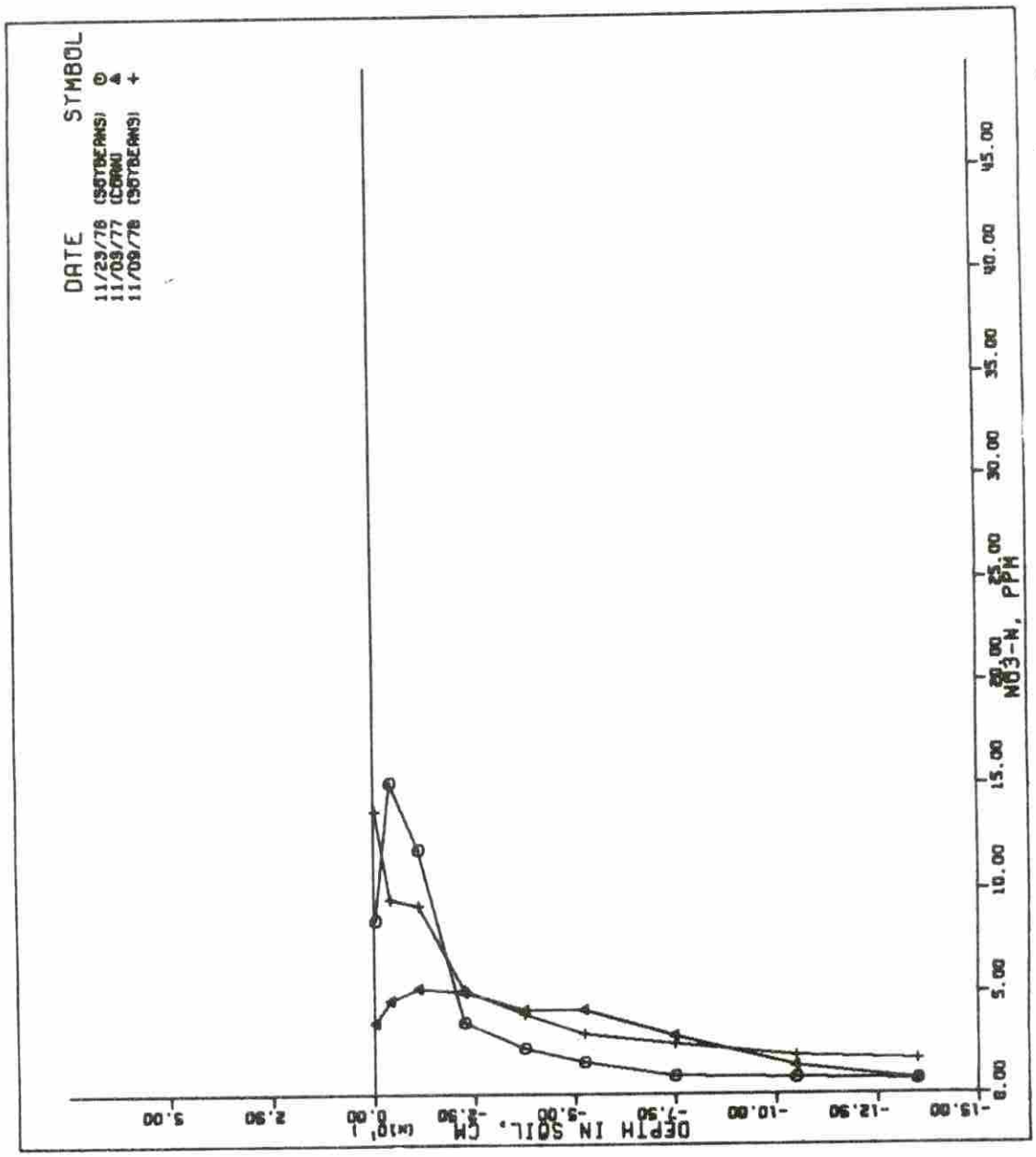


Figure 8. Soil NO3-N concentration depth profiles at site 1, November 1976, 1977, and 1978

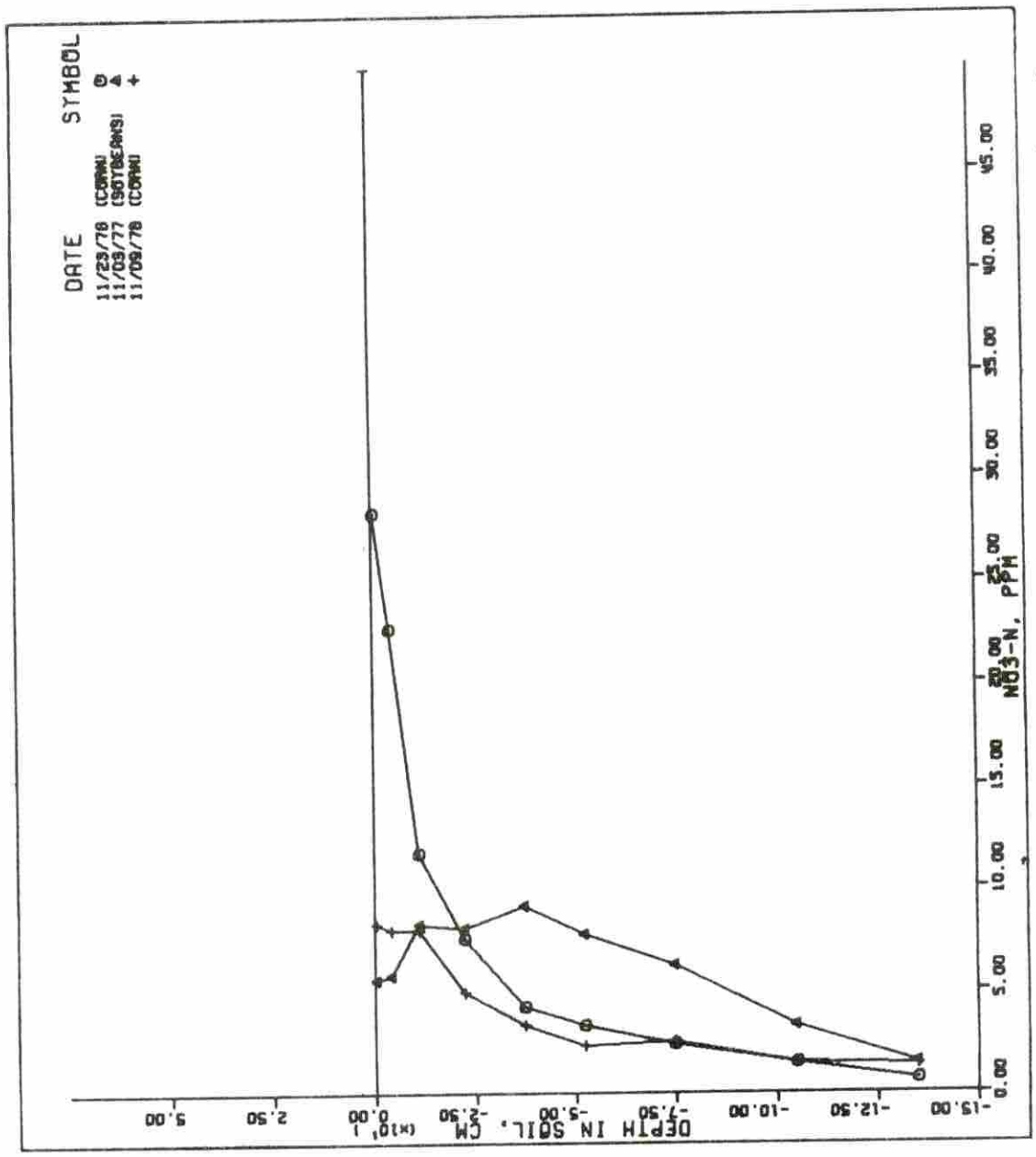


Figure 9. Soil NO3-N concentration depth profiles at site 2, November 1976, 1977, and 1978

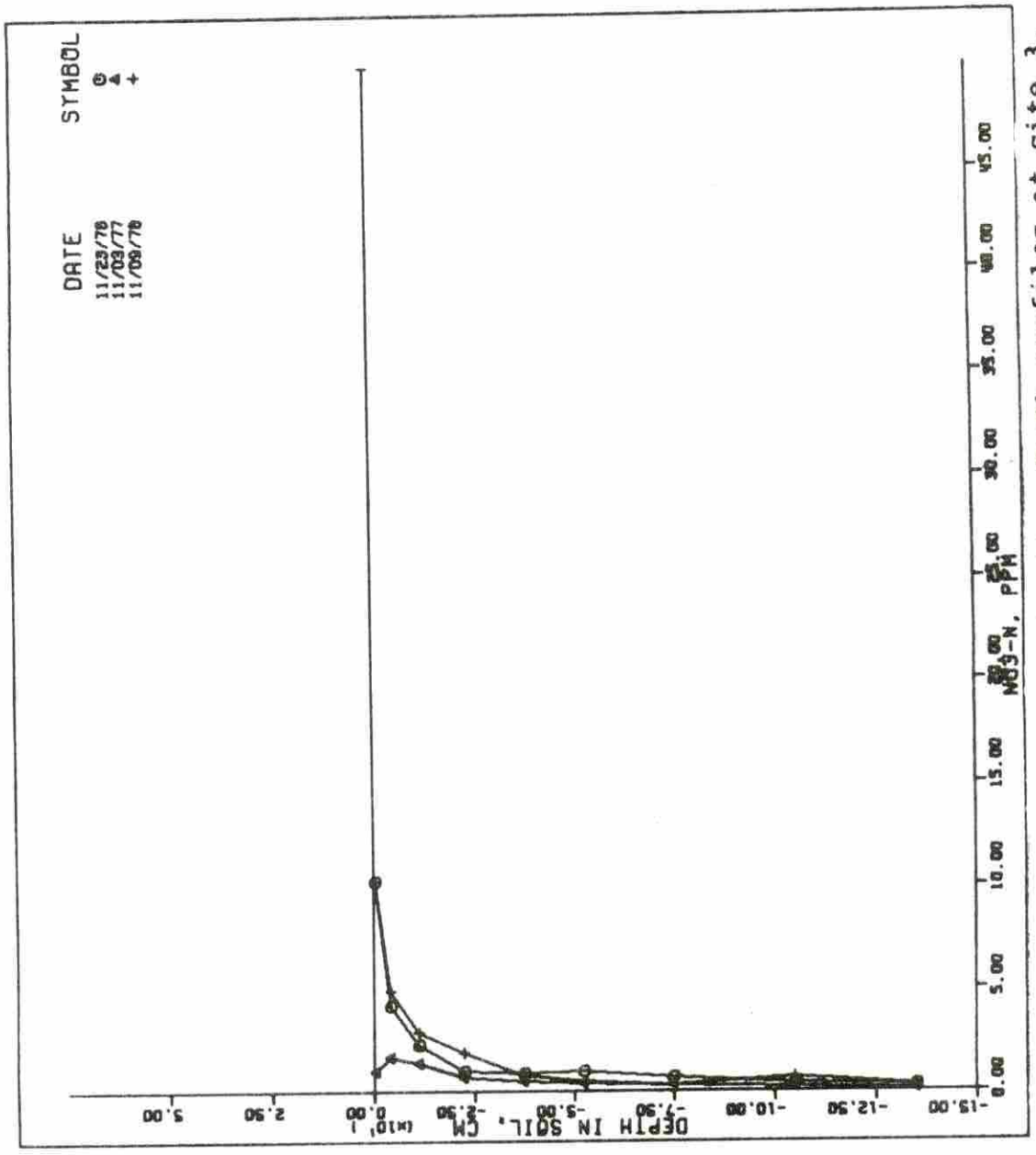


Figure 10. Soil NO3-N concentration depth profiles at site 3, November 1976, 1977, and 1978

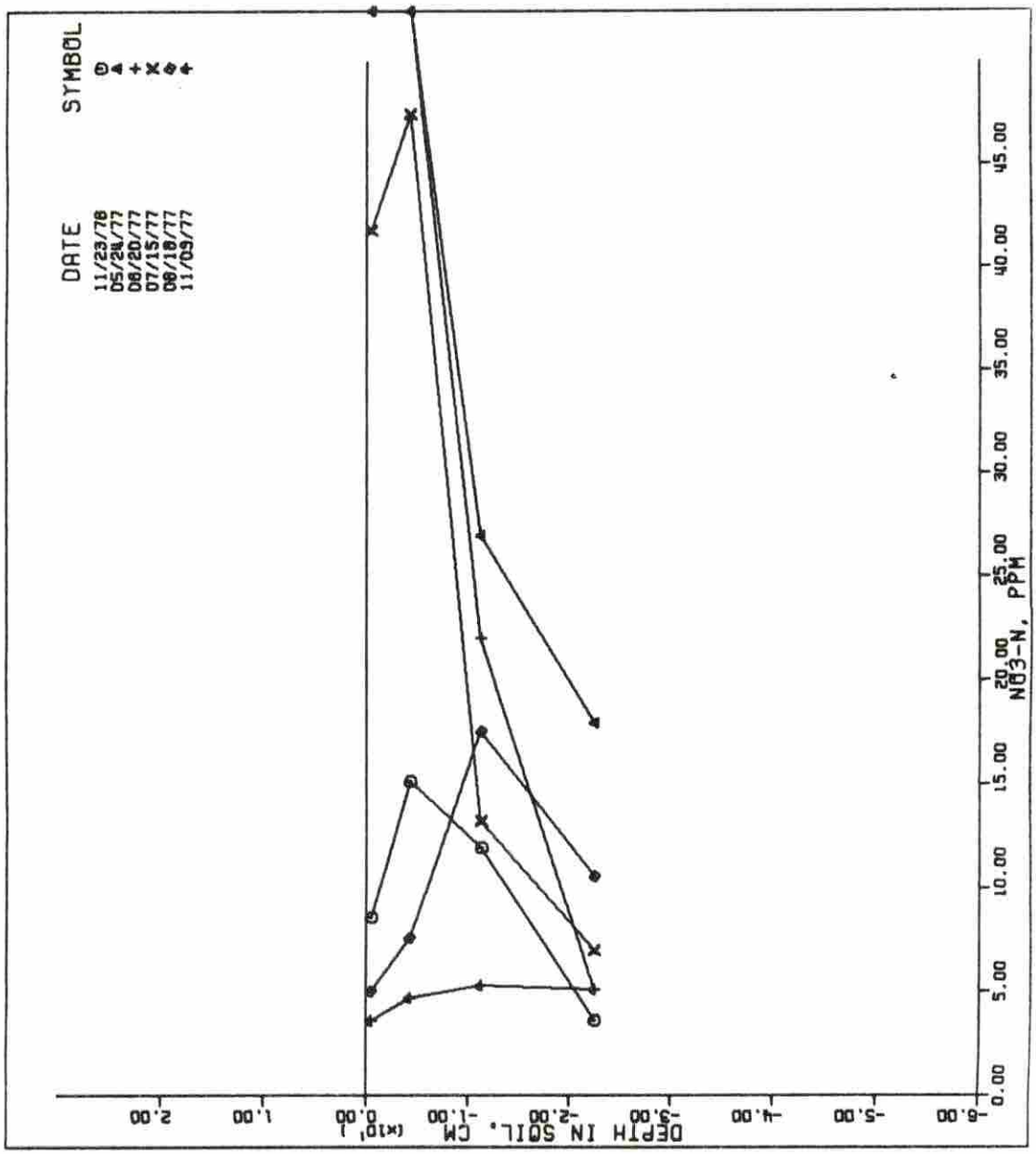


Figure 11. Soil NO3-N concentration shallow depth profiles at site 1, fall 1976 through 1977

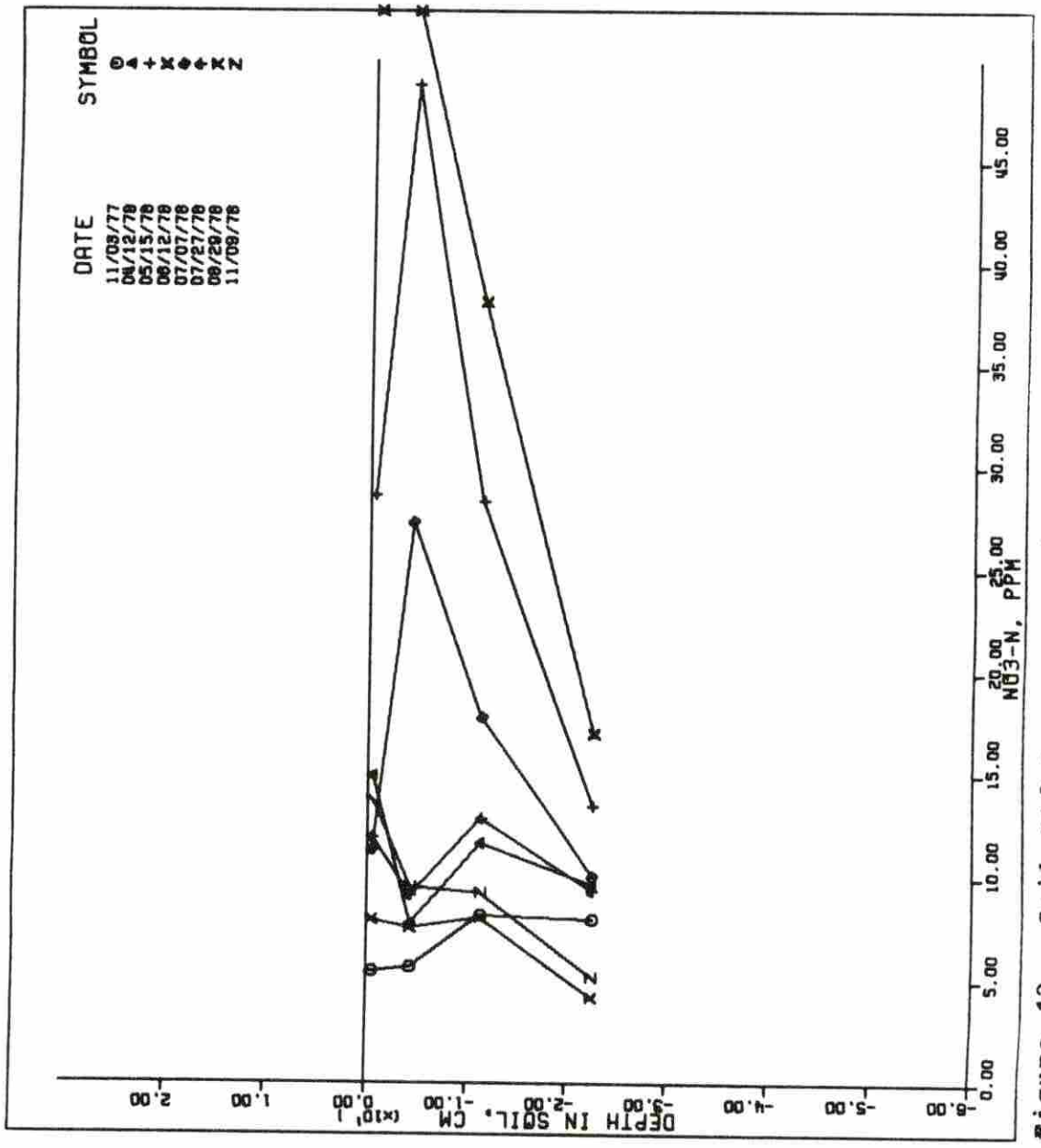


Figure 12. Soil NO3-N concentration shallow depth profiles at site 2, late 1977, through 1978

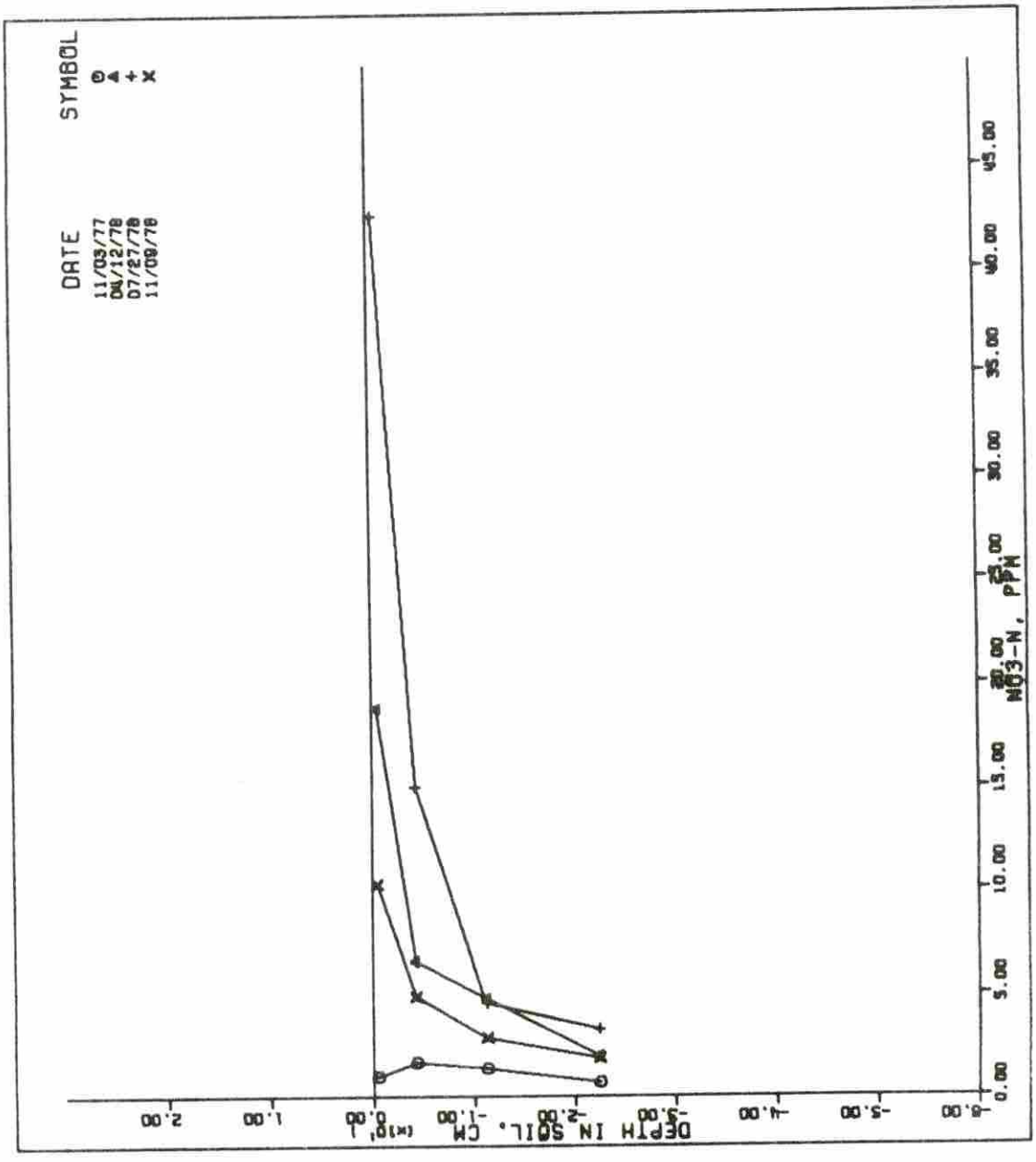


Figure 13. Soil NO3-N concentration shallow depth profiles at site 3, late 1977, through 1978

of the 3 sites during the 3 years of the study.

Since most of the change in NO3-N concentrations occurred in the upper layers of the soil profile, comparisons of the NO3-N concentrations in the top 30 cm at site 1 in 1977, site 2 in 1978, and site 3 in 1978 are presented in Figures 11, 12, and 13. Samples of the top 30 cm were taken more frequently during the growing season, at sites 1 and 2, so the trend of increasing and then decreasing NO3-N concentrations is even more evident. Addition of fertilizer N caused the large increases in NO3-N concentrations, while crop withdrawal was probably responsible for most of the decreases. Increase in the NO3-N concentrations from the fall of 1977 to the spring of 1978 (before fertilization) at site 2 indicates that some mineralization of N may be taking place. The increase in NO3-N concentrations at site 3 from the spring to the summer of 1978 may not be entirely due to fertilization; the same trend occurred in 1976 when no fertilizer N was applied, indicating that mineralization of N may also be at least partially responsible for the increase in NO3-N concentrations.

Fertilizer P applied to sites 1 and 2 was incorporated within the upper 15 to 20 cm of the soil profile by either disking or plowing. Fertilizer P applied to site 3 was not incorporated. Phosphorus has been found to be a relatively immobile nutrient (Welch et al., 1966), therefore the

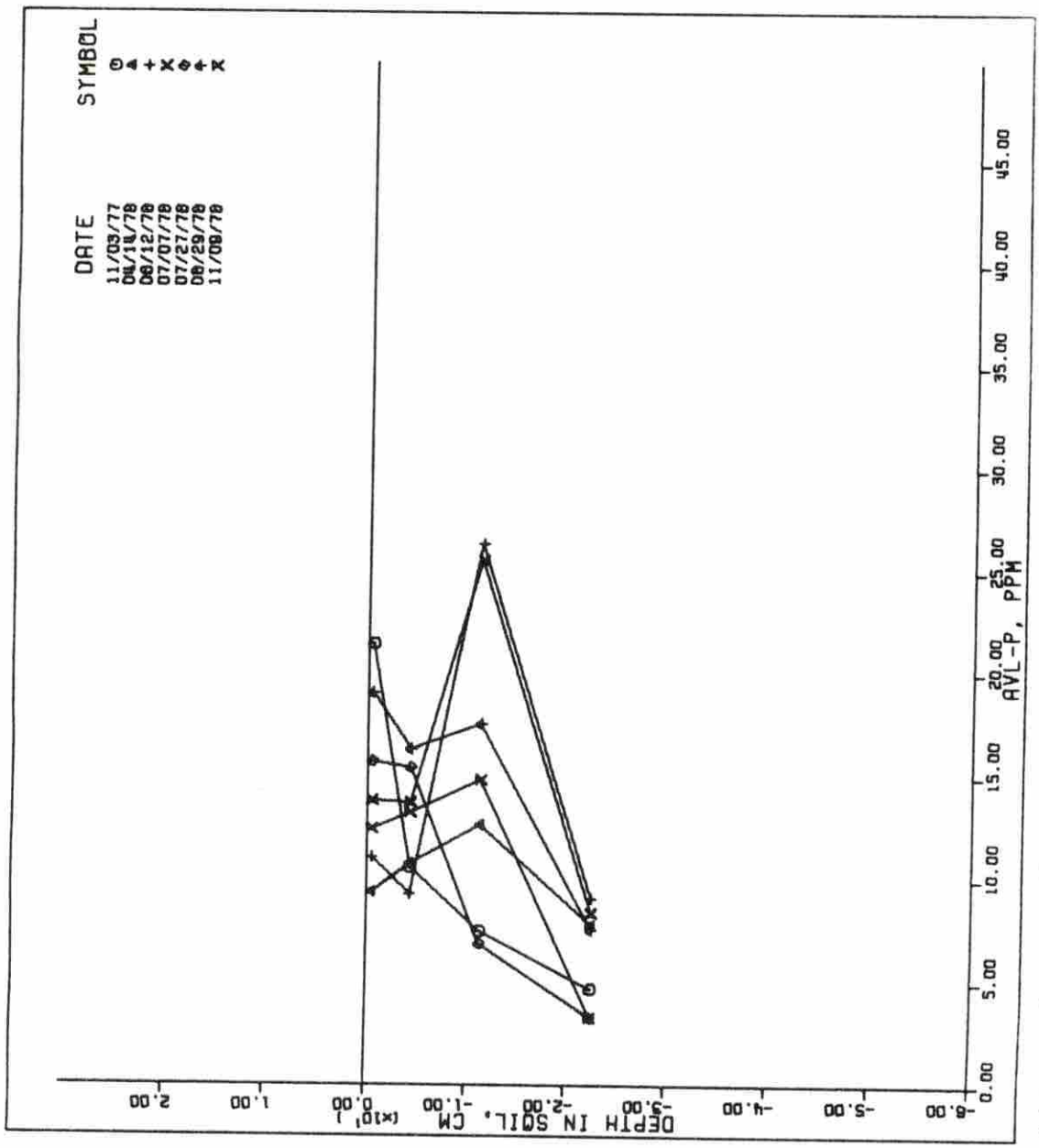


Figure 14. Soil AVL-P concentration shallow depth profiles at site 1, late 1977, through 1978

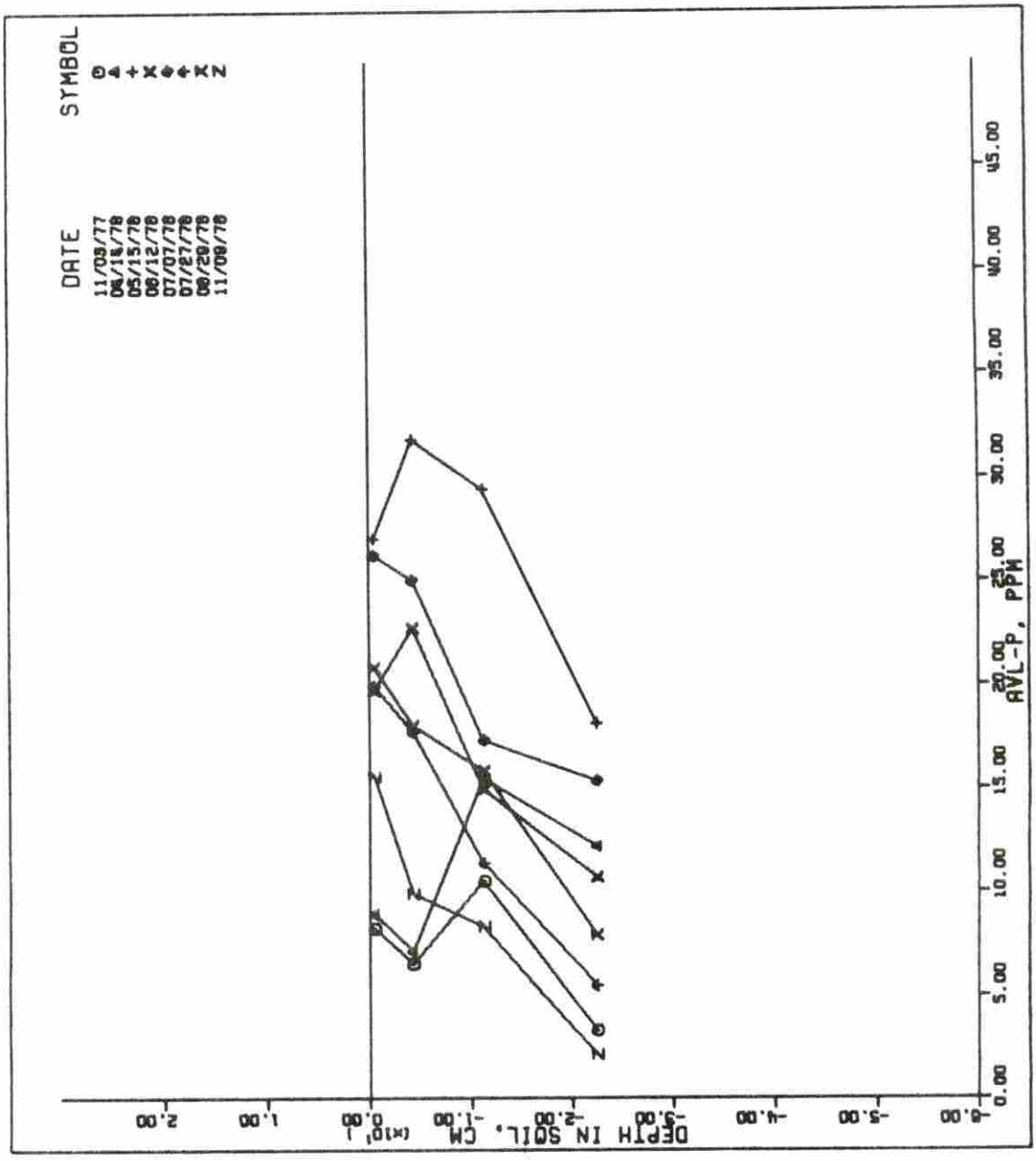


Figure 15. Soil AVL-P concentration shallow depth profiles at site 2, late 1977, through 1978

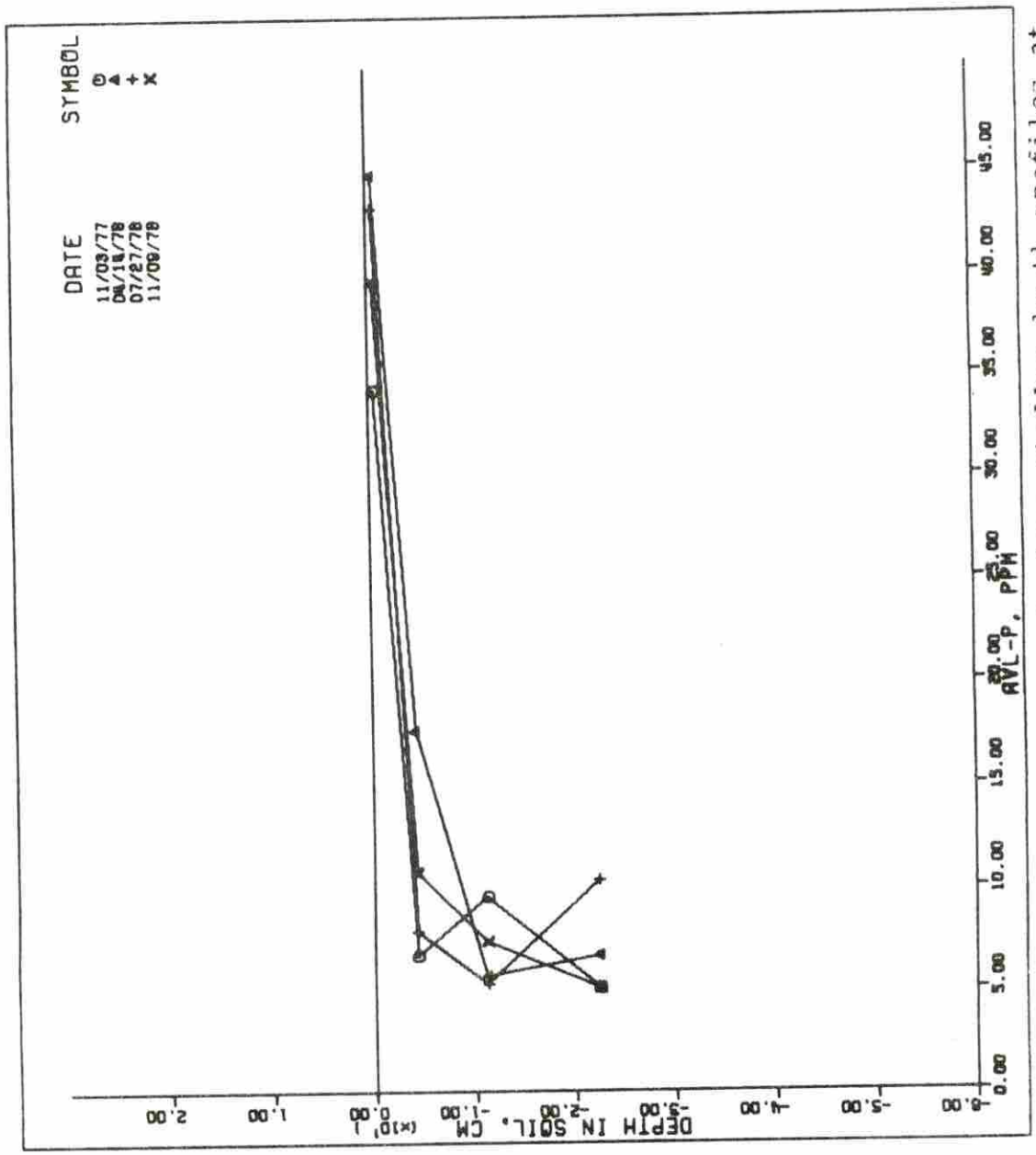


Figure 16. Soil AVL-P concentration shallow depth profiles at site 3, late 1977, through 1978

fertilizer P should have remained within the upper 30 cm of the soil profile. Since there were very small amounts of soluble P in the soil profile at any given time, the discussion of P will be concerned mainly with the levels of AVL-P in the soil. Figures 14, 15, and 16 present the average AVL-P concentrations in the upper layers (0-1, 1-7.5, 7.5-15, and 15-30 cm) of the soil profile during various times of the 1978 growing season at sites 1, 2, and 3. Soil samples were taken more frequently at sites 1 and 2 during 1978 providing more evidence of possible changes in concentrations of AVL-P as the growing season progressed, than in previous years. Large increases in concentrations of AVL-P early in the growing season at sites 1 and 2 were quite evident, and can probably be attributed to application of fertilizer P. The decreases were probably due to crop withdrawal. No trends can be established at site 3 due to the variability in the AVL-P concentrations (Table 7), possibly due to animal wastes.

To determine whether fertilization caused accumulation of AVL-P in the upper 30 cm of the soil profile, comparisons of the AVL-P concentrations at the end of the growing seasons at each site were made. The average AVL-P concentrations in the upper 30 cm of the soil profile for the final sampling date for each growing season at sites 1, 2, and 3 are presented in Figures 17, 18, and 19. At site 1 the average AVL-P concentration in the 0-1 cm layer for November 1977 is

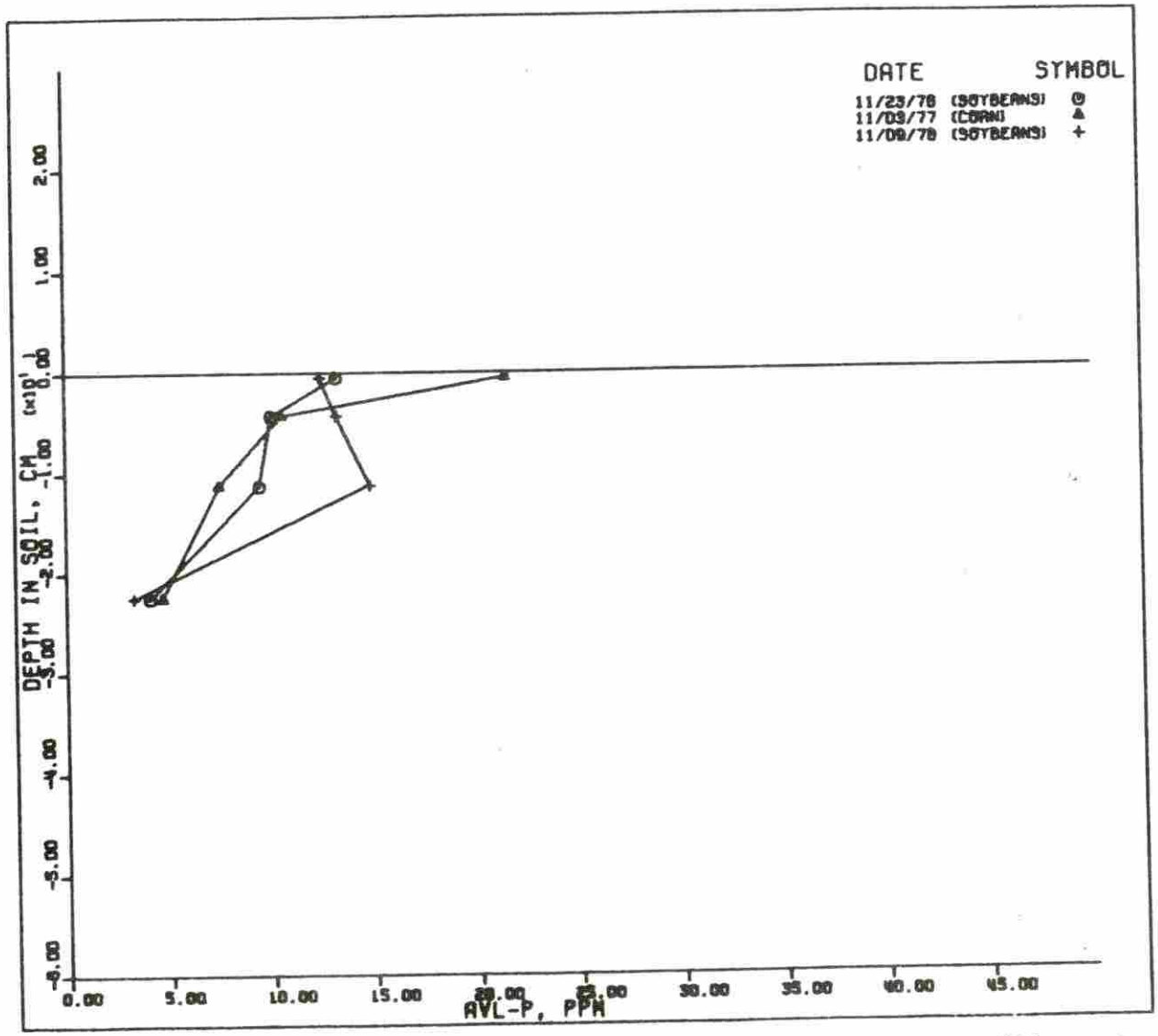


Figure 17. Soil AVL-P concentration shallow depth profiles at site 1, November 1976, 1977, and 1978

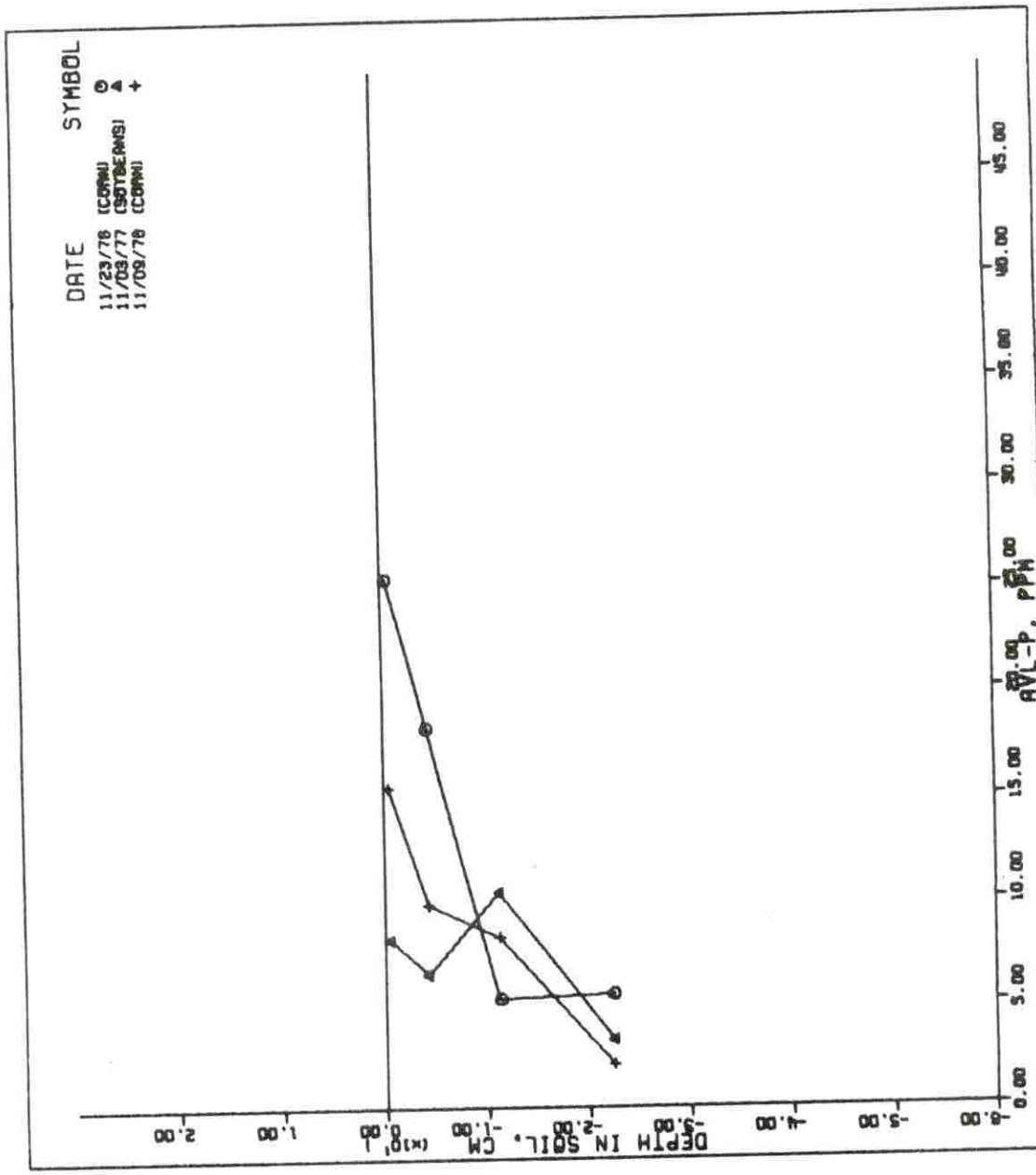


Figure 18. Soil AVL-P concentration shallow depth profiles at site 2, November 1976, 1977, and 1978

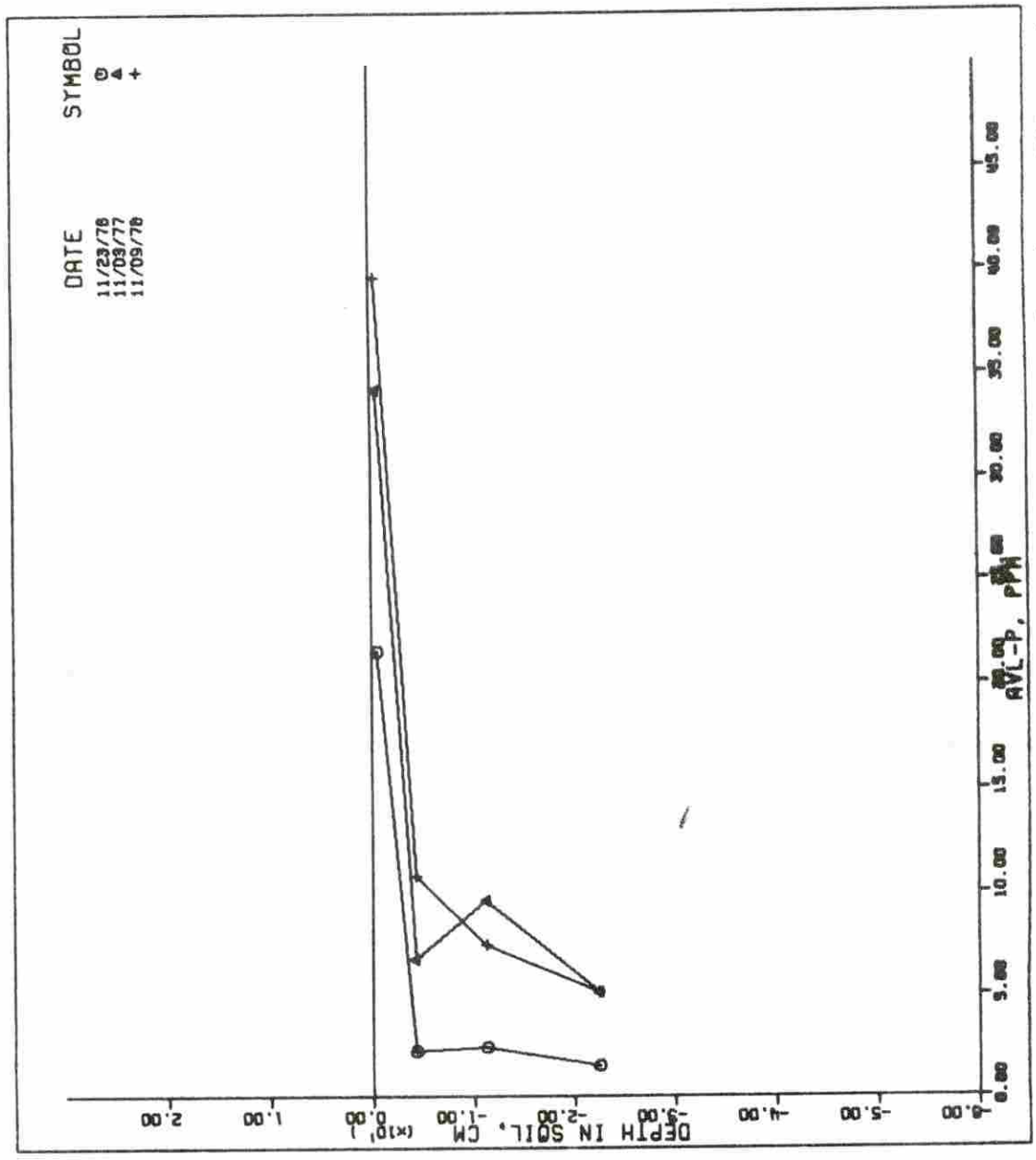


Figure 19. Soil AVL-P concentration shallow depth profiles at site 3, November 1976, 1977, and 1978

significantly higher than for November 1976 and November 1978, at the 1% level of confidence. The higher average concentration occurred in the same growing season in which fertilizer P was incorporated by disking rather than plowing. Site 2 also had significantly higher AVL-P concentrations (5% level of confidence) in the 0-1 cm layer during the years in which the fertilizer was incorporated by disking (1976 and 1978). The average AVL-P concentration in the 1-7.5 cm layer at site 2 for 1976 is also significantly higher than for the other 2 years (1% level of confidence). The 7.5-15 cm layer at site 1 in 1978 contained a significantly higher concentration of AVL-P than in 1977 (5% level of confidence). The increase in the 7.5-15 cm layer can probably be attributed to deeper incorporation of the fertilizer P by plowing. It should be noted that the rate of fertilizer P applied to the disked ground was slightly higher than that applied to the plowed ground. The difference may be offset at the end of the season, however, because the corn grown on the disked ground utilized more P than the soybeans grown on the plowed ground.

The average concentration of AVL-P in the 0-1 cm layer at site 3 appears to be increasing each year, however large variability in the samples, possibly due to animal wastes, makes it difficult to establish statistical differences. The 1-7.5 cm layer contained a significantly higher level of AVL-

P in November 1978 than in November 1976 (1% level of confidence). The 15-30 cm layer also contained a significantly higher concentration of AVL-P in both 1977 and 1978 than in 1976 (1% level of confidence). Since the fertilizer P was spread on the surface of the pasture, the increase in AVL-P in the 15-30 cm layer is difficult to explain.

The amount of AVL-P (kg/ha) in the upper 30 cm of the soil profile was also calculated (Table 9). Even though there were some significant changes in the concentrations of AVL-P in some layers from one fall to the next, there did not appear to be any significant increase in the total amount of AVL-P present in the upper 30 cm at sites 1 and 2. The total amount of AVL-P at site 3, however, was significantly higher in 1977 and 1978 than in 1976 (1% level of confidence). Since no fertilizer P was added in 1976, some of the increase in available P may be due to fertilization.

The fate of the fertilizer P applied to the upper layers of the soil profile may be affected by the amount of AVL-P in the lower layers (30-150 cm). No trends could be established, however, between the AVL-P content in the lower layers and the decrease of AVL-P in the upper layers due to crop withdrawal. The distribution of AVL-P in the lower layers of the soil profile, as determined from the soil core samples, appeared to be correlated with position on the landscape. The samples taken near the waterways at sites 1,

2, and 3 had very low concentrations of AVL-P in the lower layers of the profile. The samples taken on the upland portion of the fields contained much higher concentrations of AVL-P in the lower layers of the profile. Table 10 presents the distribution of AVL-P in the soil profile at 2 sampling locations at sites 1, 2, and 3, for the November 1976 sampling date. The distribution of AVL-P in the soil profile at a sampling location remains quite similar for all of the sampling dates.

Subsurface Loss of Nitrogen and Phosphorus

The soil core samples indicated that movement of NO3-N occurred in the upper layers of the profile. Tile water extracted from the tile lines draining the waterways at sites 1 and 2 contained NO3-N and very small amounts of PO4-P (0.03 ppm) and NH4-N (0.01 ppm). The tile did not flow until the fall of 1977, due to unusually dry moisture conditions. The concentrations of NO3-N in the tile water in the fall of 1977 averaged 7.7 and 18.1 ppm at sites 1 and 2, respectively. A comparison of NO3-N in the soil profile and in the tile water indicated that the tile lines were intercepting water equivalent to that at about the 90 cm depth. In 1978 the NO3-N levels in the tile water remained relatively constant at site 1, but decreased as the growing season progressed at site 2. The NO3-N concentrations at site 2 in the fall of 1978 ranged from 6 to 8 ppm, again indicating that water from the 90 cm

level in the soil was being intercepted by the tile lines at both sites.

The loss of NO3-N through the tile lines was negligible in 1976 and 1977 because of low flows. In 1978, some NO3-N was lost in the tile flow, however no measurements of flow were made.

Baker and Johnson (1977) estimated that tile discharge contributes about 30 to 80% of the total drainage from fairly level tile drained land in the humid region. Using an estimate of 50% contribution, the total loss of NO3-N through the tile was probably less than 5 kg/ha/yr in 1978, with the concentrations present. Total loss of NH4-N and PO4-P through the tile was negligible all three years due to the very low concentrations in the tile water.

Surface Runoff Loss of Nitrogen and Phosphorus

Nutrient losses associated with surface runoff at the 3 sites are presented in Tables 11 and 12. Surface runoff during 1977 was extremely low at sites 1 and 2, due to lack of snowmelt and an abnormally low amount of precipitation in the spring and early summer. The pasture at site 3 normally produces lower amounts of runoff, except in 1977 when an unusually severe rainstorm occurred at that site and not at sites 1 and 2.

Soluble nutrient losses in the surface runoff at the 3 sites were extremely low compared to the amount of fertilizer applied. Soluble NO3-N concentrations were much lower than those found in the tile flow from the sites. Soluble NH4-N and PO4-P concentrations were also low, except in 1977 at site 1, when a runoff event occurred shortly after fertilizer application. Soluble NH4-N and PO4-P concentrations were generally higher at site 3 than at sites 1 and 2, possibly due to animal wastes on the surface of the ground.

Losses of total N associated with the sediment accounted for a large percentage of the total losses of N from the fields; 68 to 95% from the corn, and 58 to 100% from the soybeans. N losses, both soluble and total, were generally higher from the fields planted to corn than the fields planted to soybeans.

Losses of AVL-P associated with the sediment usually accounted for a large percentage of the total P loss. The total loss of P, however, was very low for all years (1976-1978) at all 3 sites, never greater than 1% of the fertilizer applied.

The loss of N and P associated with surface runoff at the 3 sites for the three years of the study was very low compared to the amount of fertilizer N and P applied. The losses of nutrients in surface runoff seldom exceeded the amount deposited with precipitation (Table 2). The results

showed, however, that losses of N and P with sediment can be significant if heavy rainfall occurs in the spring and early summer. Surface runoff was not a major pathway for loss of fertilizer N and P from sites 1, 2, or 3 in the 3 years of the study.

SUMMARY AND CONCLUSIONS

The results from the first three years of the study have provided a good indication of the fate of fertilizer applied N and P on 3 small, field-sized watersheds.

The amount of N utilized by the corn crops (grain and residue) more than accounted for the fertilizer N applied. If the root systems of the crops were also included, the amount of N utilized was even higher. Since the N in the residue and roots will eventually be recycled through microbial action, the main concern was the amount of N removed with the grain. The amount of N removed in the corn grain amounted to 87 to 95% of the annual application rate, leaving a very small amount of N available for loss to the environment. Further study of the soil core samples indicated that no significant accumulation or deep leaching of N in the soil profile occurred. A small amount of N was lost through tile flow, and there was probably a small amount lost due to denitrification during wet periods. Surface runoff losses of N were also low, seldom exceeding the amount of N deposited with precipitation. With the rates of fertilizer N applied, and under the field conditions present at the time of the study, the majority of fertilizer N appears to have been utilized by the crops, with only a very small loss to the environment.

The amount of P utilized by the corn and soybean crops amounted to a significant portion of the fertilizer P applied each year. The corn crops utilized more P than the soybean crops. Analysis of the soil core samples indicated that no accumulation of AVL-P was occurring in the top 30 cm of the soil profile at sites 1 and 2. The soil core samples did indicate, however, that the concentrations of AVL-P in different layers in the upper part of the soil profile may be dependent on recent tillage actions. The soil core samples taken at site 3 indicated that there may have been an increase in AVL-P in the top 30 cm of the soil profile. No apparent downward movement of P in the profile occurred at any of the sites, and there was no significant loss of P through the tile lines. Surface runoff loss of P was very low, usually less than the amount of P deposited with precipitation.

The P removed in the harvested portion of the corn and soybean crops accounted for an equivalent of 59 to 67% and 41 and 59% of the fertilizer P applied, respectively. Since there were no other significant losses or accumulations of P detected, there was still a portion of the fertilizer P unaccounted for. The unaccounted for P probably remained in the upper layers of the soil, and was reduced in solubility and made unavailable (fixed) through reactions that occurred in the soil. The fixed P may eventually become available for

plant utilization. Fixation of some fertilizer P generally occurs in most soils. If the level of fertilizer P applied continues to exceed that removed in the harvested portion of the crops, it would be expected that the AVL-P levels in the top 30 cm of the soil profile would eventually increase. The increase in AVL-P levels in the top 30 cm of the soil profile at site 3 may have been a result of P fertilization. With the rates of fertilizer P applied, and under the field conditions present at the time of the study, the majority of fertilizer P appears to have been utilized by the crops or remained in the soil, with only a very small loss to the environment.

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APPENDIX

Table 1. Annual yields, nitrogen and phosphorus content, of the corn and soybean crops at sites 1 and 2

crop	year	site	fertilizer applied N	fertilizer applied P	yield[1] grain	yield[1] residue	nitrogen content grain	nitrogen content residue	nitrogen content total	phosphorus content grain	phosphorus content residue	phosphorus content total
			kg/ha		tonnes/ha		kg/ha			kg/ha		
corn	1976	2	135	39	7.86	7.74	122 (90%)[2]	60 (44%)	182 (134%)	23 (59%)	7 (18%)	30 (77%)
corn	1977	1	135	39	7.34	6.72	118 (87%)	52 (39%)	170 (126%)	25 (64%)	6 (15%)	31 (79%)
corn	1978	2	135	39	8.14	7.84	128 (95%)	61 (45%)	189 (140%)	26 (67%)	7 (18%)	22 (85%)
soybeans	1976	1		34	2.32	2.24	151	13	164	14 (41%)	2 (6%)	16 (47%)
soybeans	1977	2		34	2.50	2.24	163	13	176	15 (44%)	2 (6%)	17 (50%)
soybeans	1978	1		34	3.32	2.24	216	13	229	20 (59%)	2 (6%)	22 (65%)

[1] Yield was calulated on an oven dry basis.

[2] % of annual application of N and P.

Table 2. Average concentrations and annual amounts of soluble nutrients and suspended solids in precipitation

year	depth of precipitation	nitrogen				phosphorus		suspended solids	
		NH_4-N		NO_3-N		PO_4-P			
	mm	ppm	kg/ha	ppm	kg/ha	ppm	kg/ha	ppm	kg/ha
1976	554	0.78	4.20	0.76	4.10	0.054	0.29	26	144
1977	828	0.87	7.20	1.00	8.30	0.028	0.23	36	302
1978	878	0.78	6.85	0.77	6.76	0.063	0.55	50	439

Table 3. Average soil extractable NH4-N concentrations and standard deviations in the 30 cm soil profiles at site 1, fall 1976 through 1977, and site 2, fall 1977 through 1978

site	soil layer cm	extractable NH4-N ppm						
		11/23/76	5/24/77	6/20/77	7/15/77	8/18/77	11/3/77	
1	0-1	5.8[1]	52.8	11.1	6.1	1.4	1.4	
		(3.7)[2]	(6.0)	(7.6)	(1.2)	(0.8)	(3.7)	
1	1-7.5	1.1	2.5	2.5	1.3	0.6	0.6	
		(0.2)	(2.1)	(0.8)	(0.2)	(0.1)	(0.2)	
1	7.5-15	1.6	1.9	3.2	1.4	0.4	0.7	
		(0.5)	(1.0)	(1.2)	(0.4)	(0.1)	(0.3)	
1	15-30	1.7	1.8	1.9	1.8	0.5	1.7	
		(0.5)	(0.7)	(0.1)	(0.7)	(0.2)	(0.2)	
		11/3/77	4/12/78[3]	5/15/78	6/12/78	7/7/78	7/27/78	8/29/78
2	0-1	0.7	51.4	27.1	11.2	0.7	2.2	2.0
		(0.3)	(1.4)	(14.3)	(7.2)	(0.2)	(1.1)	(1.2)
2	1-7.5	0.4	0.3	32.3	1.1	0.7	0.6	1.1
		(0.1)	(0.3)	(28.5)	(1.1)	(0.1)	(0.3)	(0.2)
2	7.5-15	0.4	0.2	0.8	0.9	1.7	0.7	1.7
		(0.2)	(0.2)	(0.7)	(0.9)	(0.2)	(0.7)	(0.5)
2	15-30	0.4	0.2	0.6	1.1	1.3	0.7	3.2
		(0.1)	(0.2)	(0.6)	(0.5)	(0.5)	(1.2)	(0.7)

[1] Mean value.

[2] Standard deviation.

[3] Fertilizer applied: site 1, 4/19/77; site 2, 5/1/78.

Table 4. Average soil NO3-N concentrations and standard deviations in the 150 cm soil profiles at site 1, fall 1976 through 1977

soil layer cm	11/23/76 mean	11/23/76 standard deviation	7/15/77 mean	7/15/77 standard deviation	11/3/77 mean	11/3/77 standard deviation
	NO3-N (ppm)					
0-1	330.8	156.5	41.8	50.9	3.6	0.9
1-7.5	84.1	35.0	47.5	32.0	4.7	2.1
7.5-15	27.0	6.9	13.3	6.1	5.3	1.8
15-30	18.0	8.8	7.0	4.2	5.1	2.5
30-45	14.1	7.2	5.8	5.1	4.2	2.4
60-90	5.3	3.2	2.6	2.5	2.9	1.9
90-120	1.4	0.9	1.6	2.0	1.4	1.7
120-150	1.2	0.4	0.9	0.8	0.7	0.9

Table 5. Average soil NO3-N concentrations and standard deviations in the 150 cm soil profiles at sites 1, 2, and 3, November 1976, 1977, and 1978

site	soil layer cm	11/23/76 mean	11/23/76 standard deviation	11/3/77 mean	11/3/77 standard deviation	11/9/78 mean	11/9/78 standard deviation
		NO3-N (ppm)					
1	0-1	8.6	5.3	3.6	0.9	13.8	6.4
1	1-7.5	15.2	8.0	4.7	2.1	9.6	2.4
1	7.5-15	12.0	5.9	5.3	1.8	9.3	2.0
1	15-30	3.6	1.7	5.1	2.5	5.2	2.1
1	30-45	2.3	1.4	4.2	2.4	4.0	1.6
1	45-60	1.6	1.1	4.2	3.0	3.0	1.0
1	60-90	0.9	0.6	2.9	1.9	2.5	0.9
1	90-120	0.8	0.3	1.4	1.7	1.9	0.9
1	120-150	0.7	0.2	0.7	0.9	1.7	1.0
2	0-1	28.3	16.9	5.5	3.6	8.2	2.9
2	1-7.5	22.7	13.7	5.7	3.0	7.9	2.4
2	7.5-15	11.7	9.8	8.2	3.3	7.9	2.0
2	15-30	7.5	9.0	8.0	3.2	4.9	1.8
2	30-45	4.2	5.7	9.1	2.9	3.3	1.7
2	45-60	3.3	5.2	7.7	3.6	2.3	1.0
2	60-90	2.4	4.4	6.2	3.3	2.5	1.5
2	90-120	1.5	3.1	3.3	1.8	1.5	0.6
2	120-150	0.7	1.0	1.5	1.0	1.4	0.7
3	0-1	10.3	4.9	1.0	1.3	10.3	12.7
3	1-7.5	4.2	2.9	1.7	1.6	4.9	5.3
3	7.5-15	2.3	1.9	1.4	1.0	2.9	3.8
3	15-30	1.0	1.2	0.7	1.0	1.9	2.9
3	30-45	0.9	0.9	0.5	0.9	0.8	0.9
3	45-60	1.0	1.1	0.4	0.7	0.5	0.7
3	60-90	0.7	0.7	0.3	0.5	0.3	0.5
3	90-120	0.4	0.1	0.2	0.3	0.7	0.9
3	120-150	0.3	0.1	0.1	0.2	0.3	0.3

Table 6. Average soil NO3-N concentrations and standard deviations in the 30 cm soil profiles at site 1, fall 1976 through 1977, and sites 2 and 3, fall 1977 through 1978

site	soil layer cm	mean NO3-N ppm							
		11/23/76[1]	5/24/77	6/20/77	7/15/77	8/18/77	11/3/77		
1	0-1	8.6 (5.3)[2]	330.8 (156.5)	159.5 (34.2)	41.8 (50.9)	5.0 (1.5)	3.6 (0.9)		
1	1-7.5	15.2 (8.0)	84.1 (35.0)	87.8 (21.5)	47.5 (32.0)	7.6 (3.1)	4.7 (2.1)		
1	7.5-15	12.0 (5.9)	27.0 (6.9)	22.1 (4.3)	13.3 (6.1)	17.6 (5.3)	5.3 (1.8)		
1	15-30	3.6 (1.7)	18.0 (3.8)	5.1 (2.6)	7.0 (4.2)	10.6 (9.7)	5.1 (2.5)		
		11/3/77	4/12/78	5/15/78	6/12/78	7/7/78	7/27/78	8/29/78	11/9/78
2	0-1	5.5 (3.6)	15.0 (7.2)	28.7 (9.5)	336.9 (122.2)	11.4 (2.2)	12.0 (3.9)	8.0 (1.0)	13.8 (6.4)
2	1-7.5	5.7 (3.0)	5.8 (3.2)	48.8 (6.7)	57.1 (2.1)	27.4 (9.6)	9.2 (6.0)	7.6 (0.9)	9.6 (2.4)
2	7.5-15	8.2 (3.3)	11.7 (3.2)	28.4 (2.8)	38.2 (5.1)	17.9 (5.3)	12.9 (18.1)	8.1 (1.3)	9.3 (2.0)
2	15-30	8.0 (3.2)	9.7 (3.2)	13.5 (2.6)	17.1 (6.1)	10.1 (3.1)	9.4 (15.3)	4.2 (2.4)	5.2 (2.1)
3	0-1	1.0 (1.3)	18.9 (11.4)				42.7 (29.9)		10.3 (12.7)
3	1-7.5	1.7 (1.6)	6.6 (2.9)				15.1 (9.8)		4.3 (5.3)
3	7.5-15	1.4 (1.0)	4.8 (2.7)				4.6 (2.9)		2.9 (3.8)
3	15-30	0.7 (1.0)	2.0 (0.9)				3.3 (4.2)		1.9 (2.9)

[1] Fertilizer applied: site 1, 4/19/77; site 2, 5/1/78; site 3, 4/26/78.

[2] Standard deviation.

Table 7. Average soil AVL-P concentrations and standard deviations in the 30 cm soil profiles at sites 1, 2, and 3, fall 1977 through 1978

site	soil layer cm	mean AVL-P ppm							
		11/3/77	4/14/78	5/15/78	6/12/78	7/7/78	7/27/78	8/29/78	11/9/78
1	0-1	21.5 (3.3)[1]	9.4 (3.1)		11.1 (2.6)	13.9 (1.6)	15.8 (8.9)	19.1 (10.9)	12.5 (5.4)
1	1-7.5	10.6 (5.4)	10.8 (7.2)		9.3 (0.9)	13.8 (2.1)	15.5 (11.4)	16.4 (6.5)	13.3 (7.5)
1	7.5-15	7.5 (3.4)	12.7 (8.4)		26.4 (11.5)	25.6 (6.4)	6.9 (4.0)	17.6 (0.4)	14.9 (7.7)
1	15-30	4.7 (3.1)	7.8 (4.6)		9.1 (5.0)	8.4 (0.9)	3.3 (2.0)	7.6 (2.7)	3.3 (2.0)
2	0-1	8.2 (2.9)	8.9 (5.2)	27.1 (9.1)	19.8 (1.7)	26.3 (4.9)	20.0 (5.8)	20.9 (3.5)	15.6 (7.6)
2	1-7.5	6.5 (3.4)	7.1 (2.5)	31.9 (6.3)	22.8 (3.8)	25.1 (6.1)	17.8 (6.3)	18.1 (3.7)	9.9 (5.3)
2	7.5-15	10.5 (6.2)	15.5 (7.1)	29.5 (8.3)	15.0 (1.9)	17.4 (1.2)	11.4 (11.5)	15.9 (6.0)	8.3 (5.8)
2	15-30	3.3 (0.8)	12.2 (9.3)	18.2 (16.8)	10.7 (2.7)	15.4 (8.4)	5.5 (2.4)	7.9 (1.5)	2.1 (1.9)
3	0-1	34.3 (17.7)	44.8 (13.1)				43.2 (8.7)		39.7 (6.3)
3	1-7.5	6.7 (3.9)	17.7 (25.2)				7.9 (4.5)		10.8 (4.7)
3	7.5-15	9.6 (10.3)	5.7 (4.0)				5.3 (2.3)		7.4 (7.1)
3	15-30	5.1 (2.4)	6.7 (6.4)				10.4 (13.4)		5.1 (2.0)

[1] Standard deviation.

Table 8. Average soil AVL-P concentrations and standard deviations in the 30 cm soil profiles at sites 1, 2, and 3, November 1976, 1977, and 1978

site	soil layer cm	11/23/76 mean	11/23/76 standard deviation	11/3/77 mean	11/3/77 standard deviation	11/9/78 mean	11/9/78 standard deviation
		AVL-P (ppm)					
1	0-1	13.3	4.0	21.5	3.3	12.5	5.4
1	1-7.5	10.1	5.2	10.6	5.4	13.3	7.5
1	7.5-15	9.5	6.5	7.5	3.4	14.9	2.0
1	15-30	4.1	3.2	4.7	3.1	3.3	2.0
2	0-1	25.6	8.3	8.2	2.9	15.6	7.6
2	1-7.5	18.4	7.5	6.5	3.4	9.9	5.3
2	7.5-15	5.3	4.1	10.5	6.2	8.3	5.8
2	15-30	5.5	5.3	3.3	0.8	2.1	1.9
3	0-1	21.6	13.5	34.3	17.7	39.7	6.3
3	1-7.5	2.2	0.2	6.7	3.9	10.8	4.7
3	7.5-15	2.4	2.0	9.6	10.3	7.4	7.1
3	15-30	1.5	1.2	5.1	2.4	5.11	2.0

Table 9. Average total AVL-P content in the 30 cm soil profiles at sites 1, 2, and 3, November 1976, 1977, and 1978

sample location	site 1			site 2			site 3		
	1976	1977	1978	1976	1977	1978	1976	1977	1978
	AVL-P (kg/ha)								
1	35.1	48.4	49.8	66.7	23.7	37.0	8.4	49.6	22.4
2	22.0	17.1	37.1	16.0	22.0	16.2	14.0	27.8	27.7
3	12.3	17.7	19.0	16.5	14.6	12.1	6.4	30.0	36.6
4	32.6	24.0	20.2	26.7	39.8	40.7	14.3	13.3	46.9
5	27.7	32.5	28.0	36.5	14.5	19.6	5.7	28.6	24.4
6	39.8	30.6	30.2	43.5	17.3	21.5			
7	20.6	21.8	29.6	38.0	32.5	8.4			
8	26.9	37.9	66.7	38.9	29.6	29.2			
mean	28.5	28.8	35.1	35.4	24.3	23.1	9.8	29.9	31.6
standard deviation	8.8	10.8	16.1	16.4	9.1	11.6	4.1	12.9	10.1

Table 10. Soil AVL-P concentrations in the 150 cm soil profiles, November 23, 1976

soil layer cm	site 1 location[1] 4	site 1 location[1] 2	site 2 location 3	site 2 location 6	site 3 location 4	site 3 location 2
	AVL-P (ppm)					
0-1	12.1	15.9	18.2	20.5	19.7	39.0
1-7.5	7.2	7.5	12.3	18.1	2.1	1.9
7.5-15	18.9	17.5	2.2	2.1	3.8	5.1
15-30	2.7	3.0	1.0	11.4	3.1	1.5
30-45	1.6	3.8	0.4	19.9	2.3	2.1
45-60	0.8	25.3	0.1	22.6	2.4	9.9
60-90	0.5	37.2	0.1	17.2	3.3	25.0
90-120	1.2	33.1	0.7	16.0	4.6	27.8
120-150	3.0	28.3	1.5	14.1	4.2	26.4

[1] Locations 4, site1; 3, site 2; and 4, site 3 are next to the waterway

Table 11. Average concentrations and annual amounts of soluble nutrients and suspended solids in runoff

crop	year	site	depth of runoff	nitrogen NH4-N		nitrogen NO3-N		phosphorus PO4-P		suspended solids	
			mm	ppm	kg/ha	ppm	kg/ha	ppm	kg/ha	ppm	kg/ha
corn	1976	2	51.0	0.44	0.22	5.2	2.7	0.048	0.02	10440	5380
corn	1977	1	11.7	2.30	0.27	0.7	0.1	0.720	0.08	38380	4670
corn	1978[1]	2	47.1	0.60	0.28	3.4	1.6	0.118	0.06	5520	2600
soybeans	1976	1	58.4	0.09	0.05	3.5	2.0	0.028	0.02	4650	2730
soybeans	1977	2	0.9	0.10	0.00	0.3	0.0	0.040	0.00	20000	174
soybeans	1978	1	45.7	0.15	0.07	2.2	1.0	0.330	0.15	1970	900
grass	1976	3	13.0	0.20	0.03	0.9	0.1	1.160	0.15	310	40
grass	1977	3	8.6	0.66	0.06	0.4	0.0	0.940	0.08	310	27
grass	1978	3	5.4	0.56	0.03	0.6	0.0	0.926	0.05	37	2

[1] Data for 1978 are preliminary and subject to revision.

Table 12. Annual nitrogen and phosphorus losses to surface runoff

crop	year	site	nitrogen content			phosphorus content		
			sediment	water	total	sediment	water	total
			kg/ha					
corn	1976	2	8.4 (6%)[1]	2.9 (2%)	11.3 (8%)	0.2 (1%)	0.0 (0%)	0.2 (1%)
corn	1977	1	7.9 (6%)	0.4 (<1%)	8.3 (6%)	0.3 (1%)	0.1 (<1%)	0.4 (1%)
corn	1978[2]	2	4.1 (3%)	1.9 (1%)	6.0 (4%)	0.1 (<1%)	0.1 (<1%)	0.2 (1%)
soybeans	1976	1	4.6	2.1	6.7	0.1 (<1%)	0.0 (0%)	0.1 (<1%)
soybeans	1977	2	0.2	0.0	0.2	0.0 (0%)	0.0 (0%)	0.0 (0%)
soybeans	1978	1	1.5	1.1	2.6	0.0 (0%)	0.2 (1%)	0.2 (1%)
grass	1976	3	0.0	0.1	0.1	0.0	0.2	0.2
grass	1977	3	0.0 (0%)	0.1 (0%)	0.1 (<1%)	0.0 (0%)	0.1 (1%)	0.1 (1%)
grass	1978	3	0.0 (0%)	0.0 (0%)	0.0 (0%)	0.0 (0%)	0.1 (1%)	0.1 (1%)

[1] % of annual application of N and P.

[2] Data for 1978 are preliminary and subject to revision.